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(54) **SIX DEGREE OF FREEDOM AERIAL
VEHICLE**

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2201/165 (2013.01)

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2201/165; B64C 2201/027; B64C
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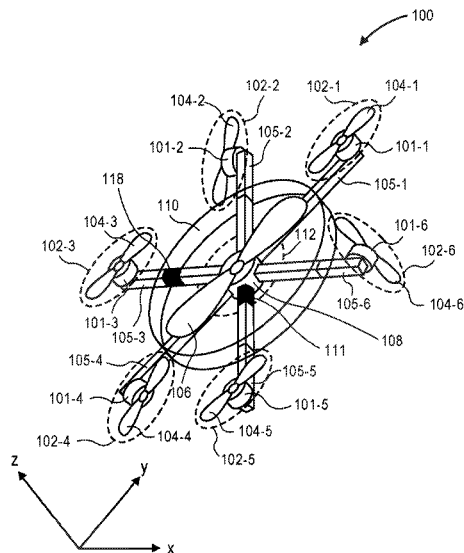
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(57) **ABSTRACT**

This disclosure describes an aerial vehicle, such as an
unmanned aerial vehicle (“UAV”), which includes a plural-
ity of maneuverability propulsion mechanisms that enable
the aerial vehicle to move in any of the six degrees of
freedom (surge, sway, heave, pitch, yaw, and roll). The aerial
vehicle may also include a lifting propulsion mechanism that
operates to generate a force sufficient to maintain the aerial
vehicle at an altitude.

18 Claims, 16 Drawing Sheets



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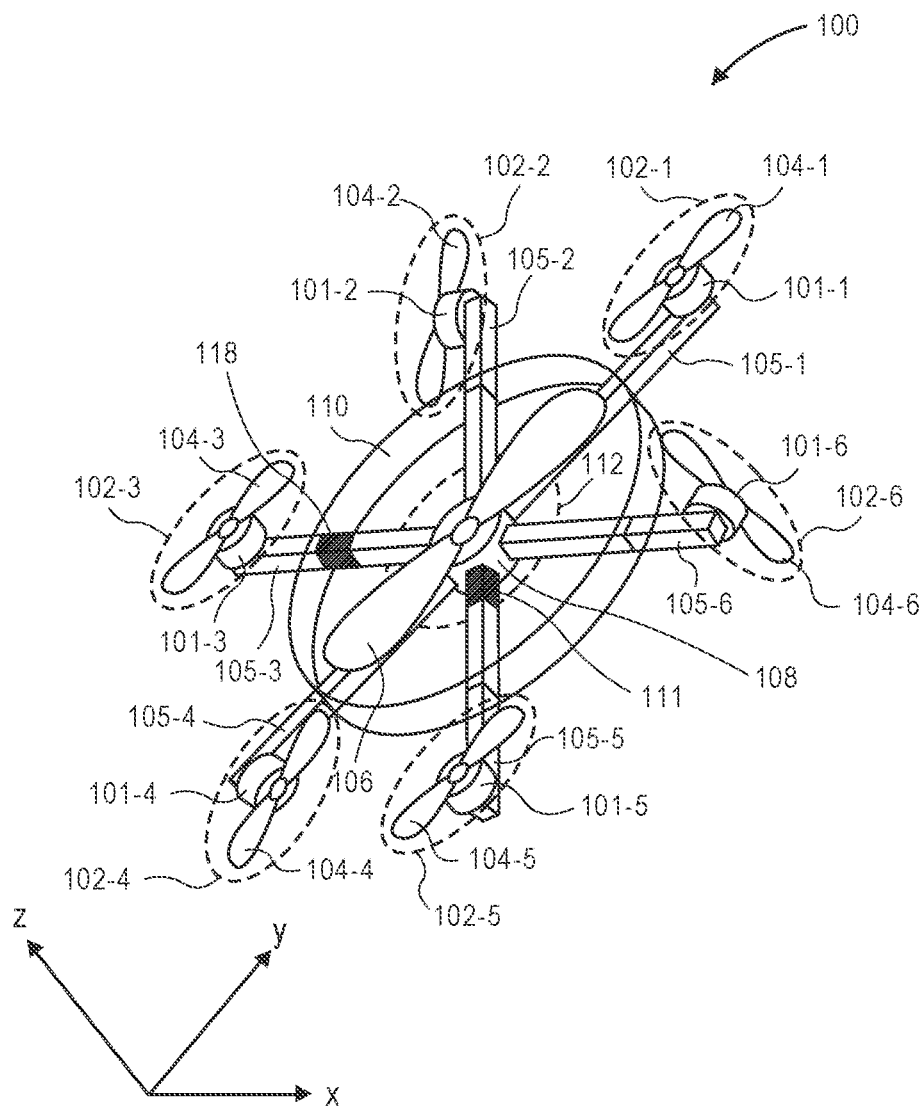


FIG. 1

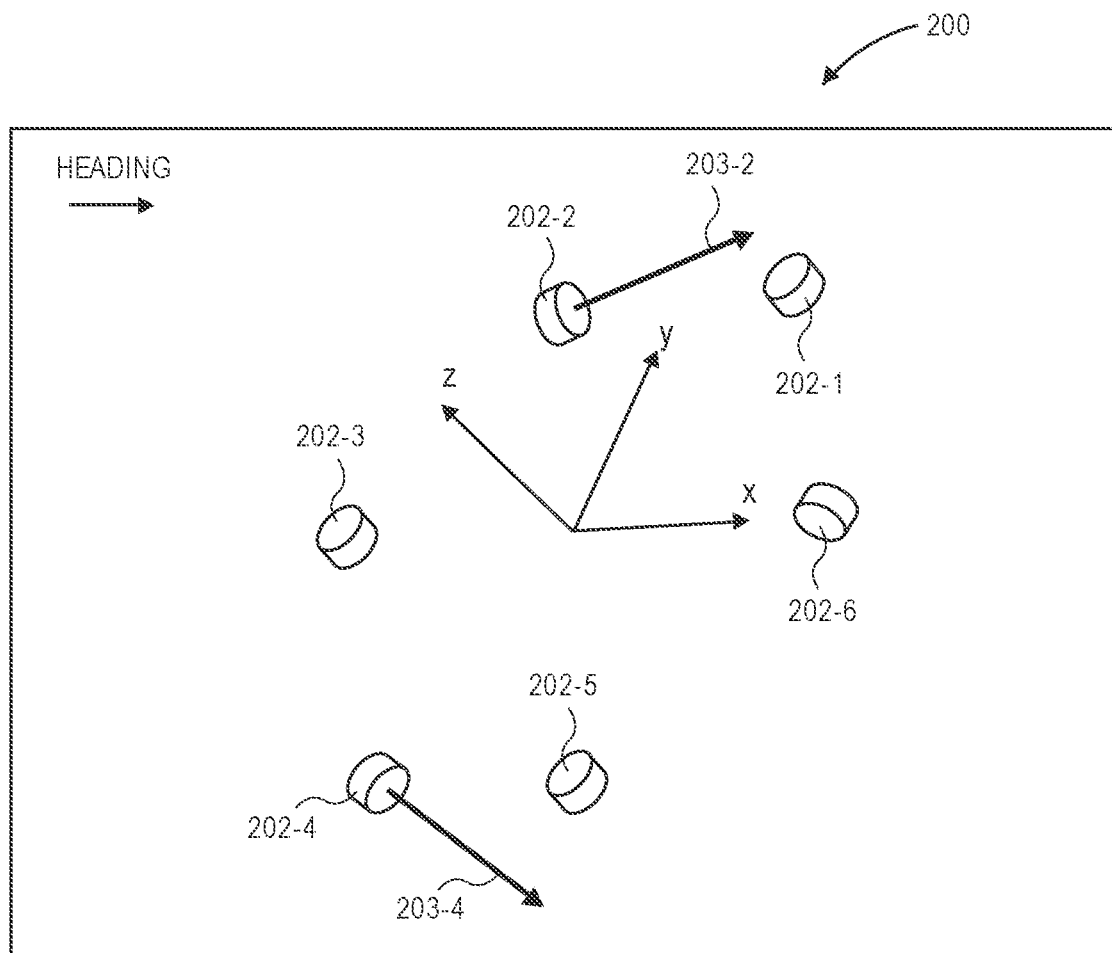


FIG. 2

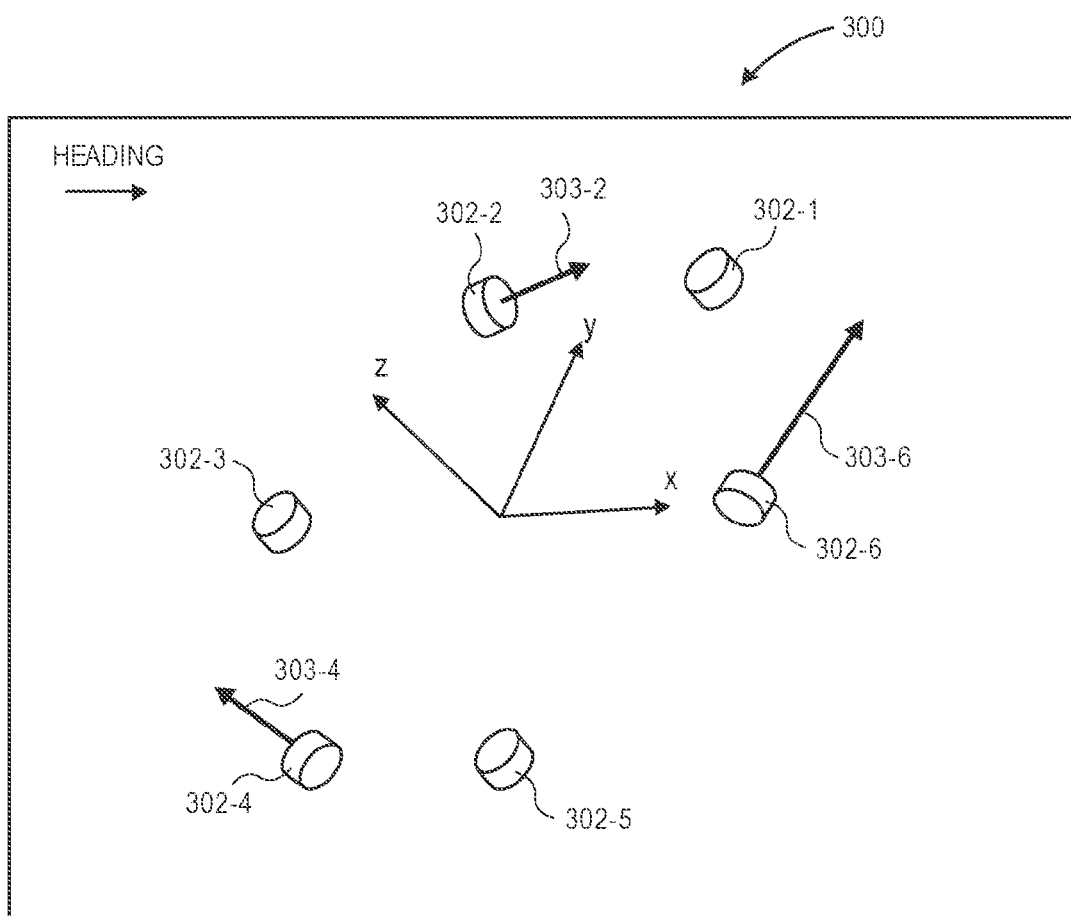


FIG. 3

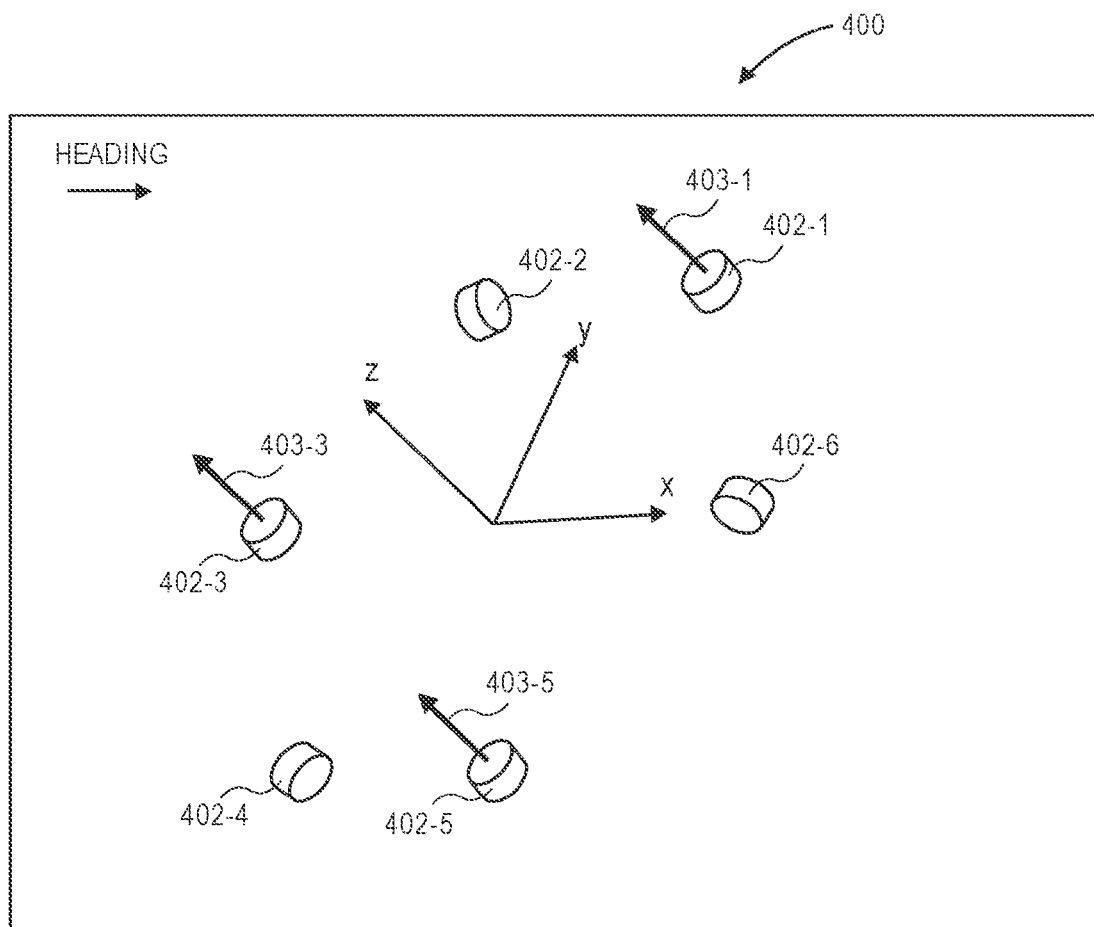


FIG. 4

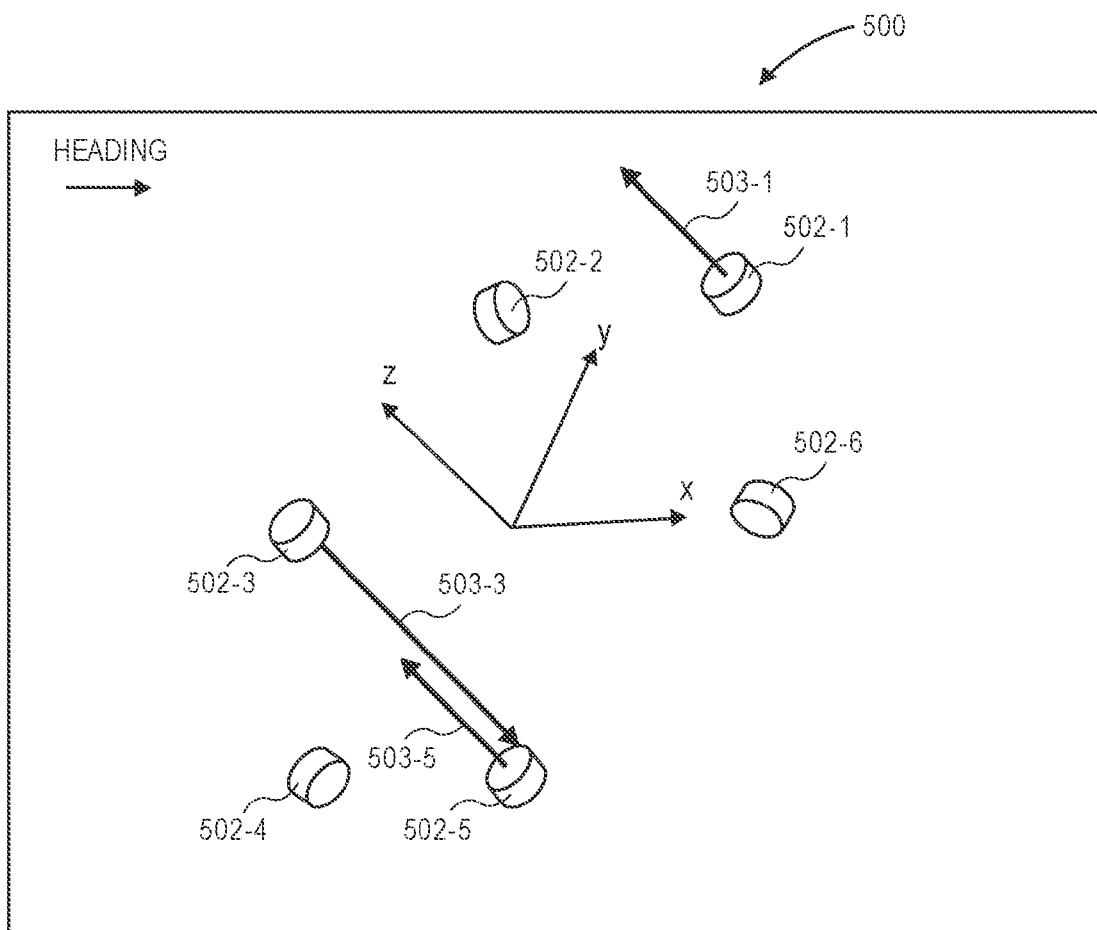


FIG. 5

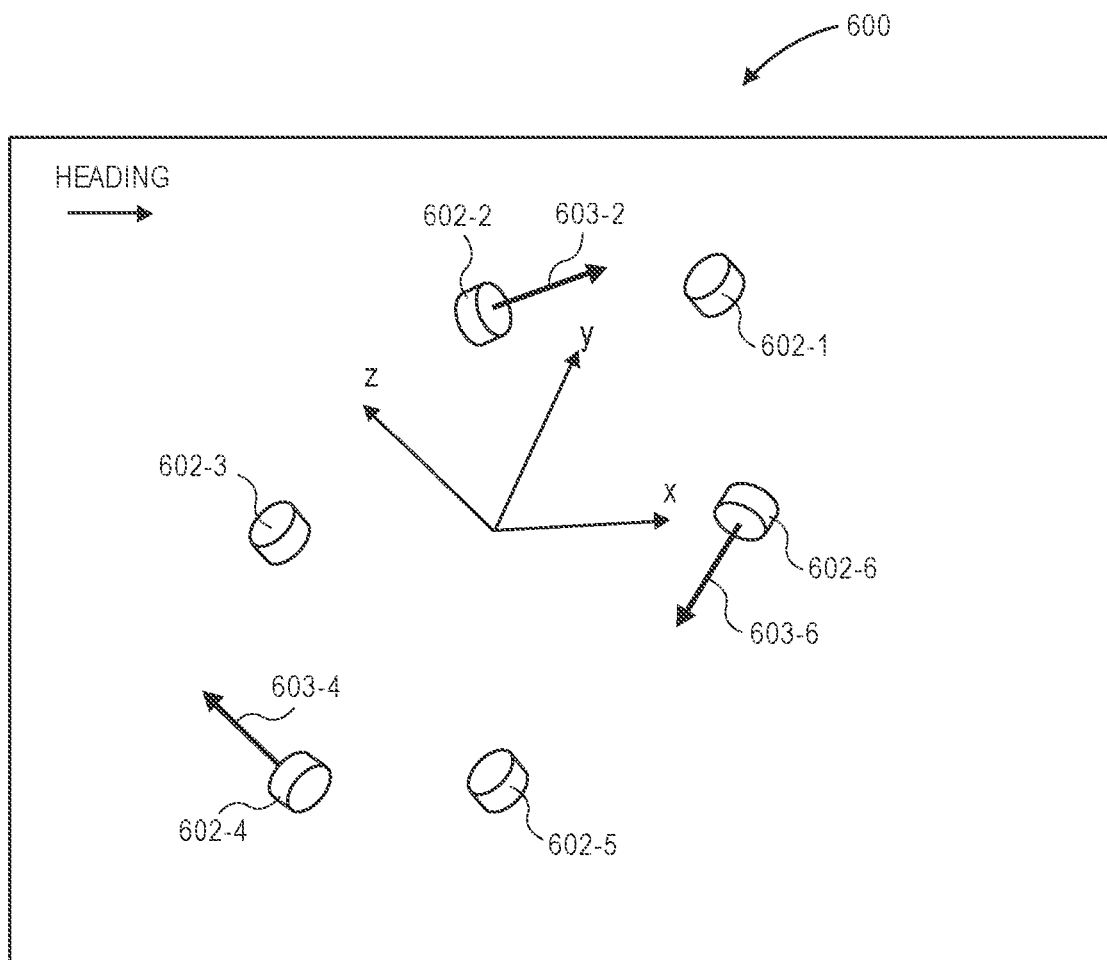


FIG. 6

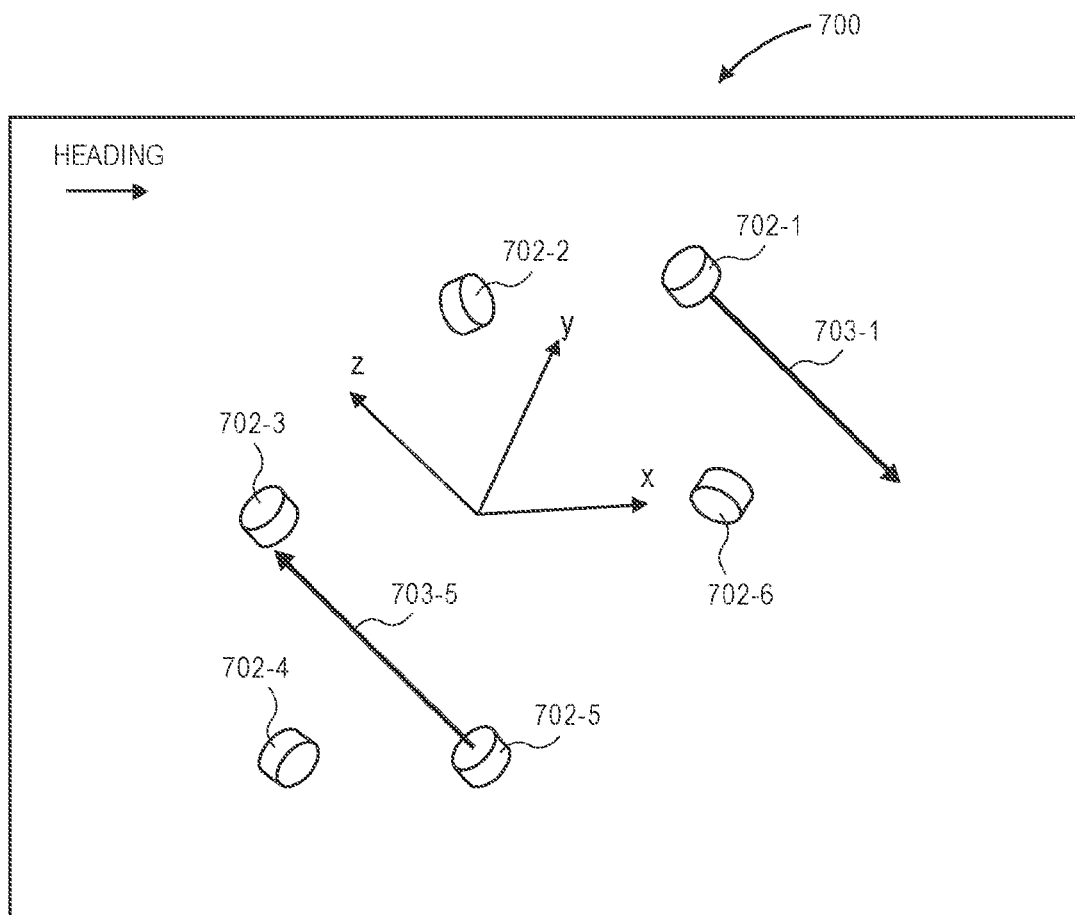


FIG. 7

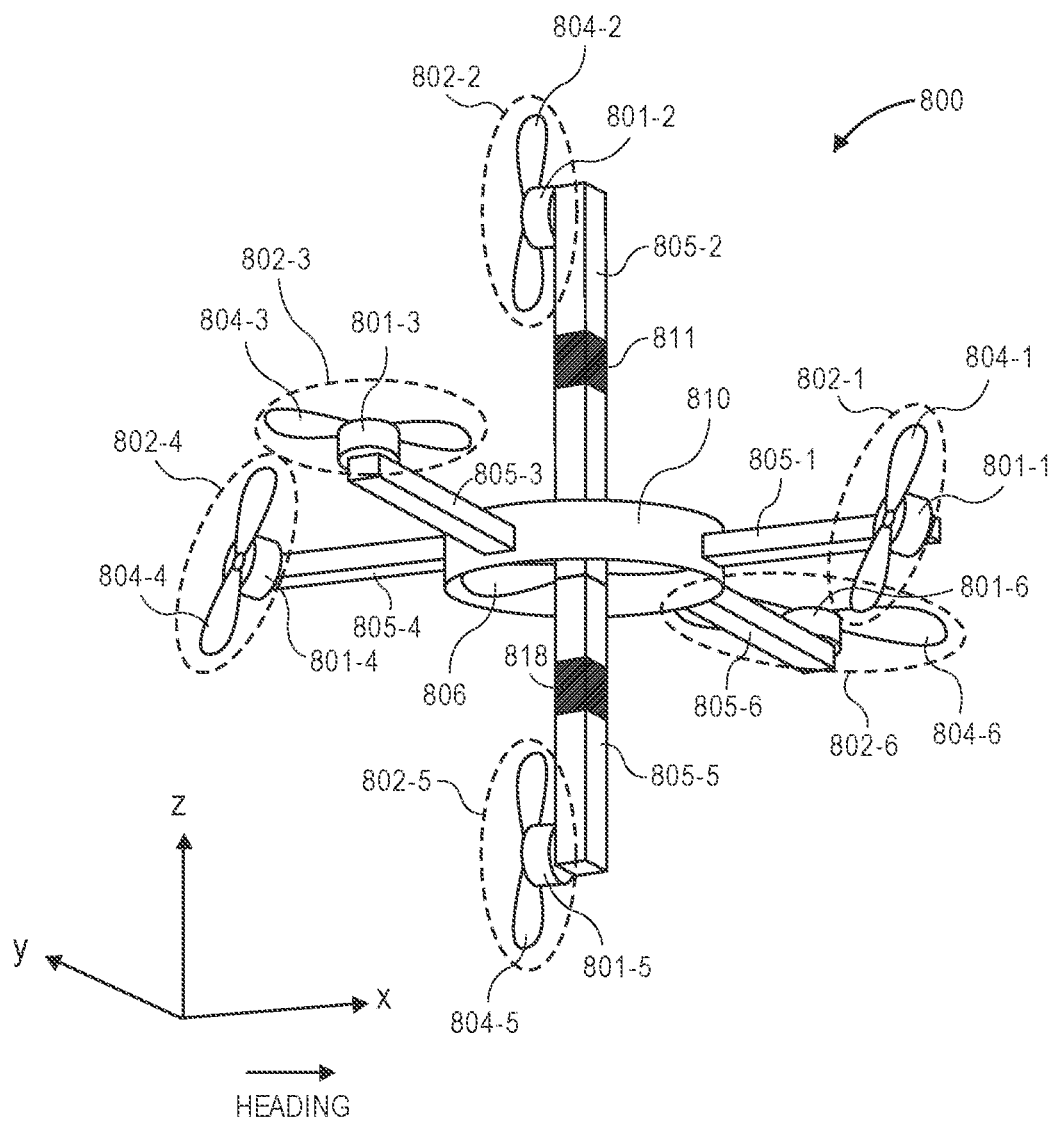


FIG. 8

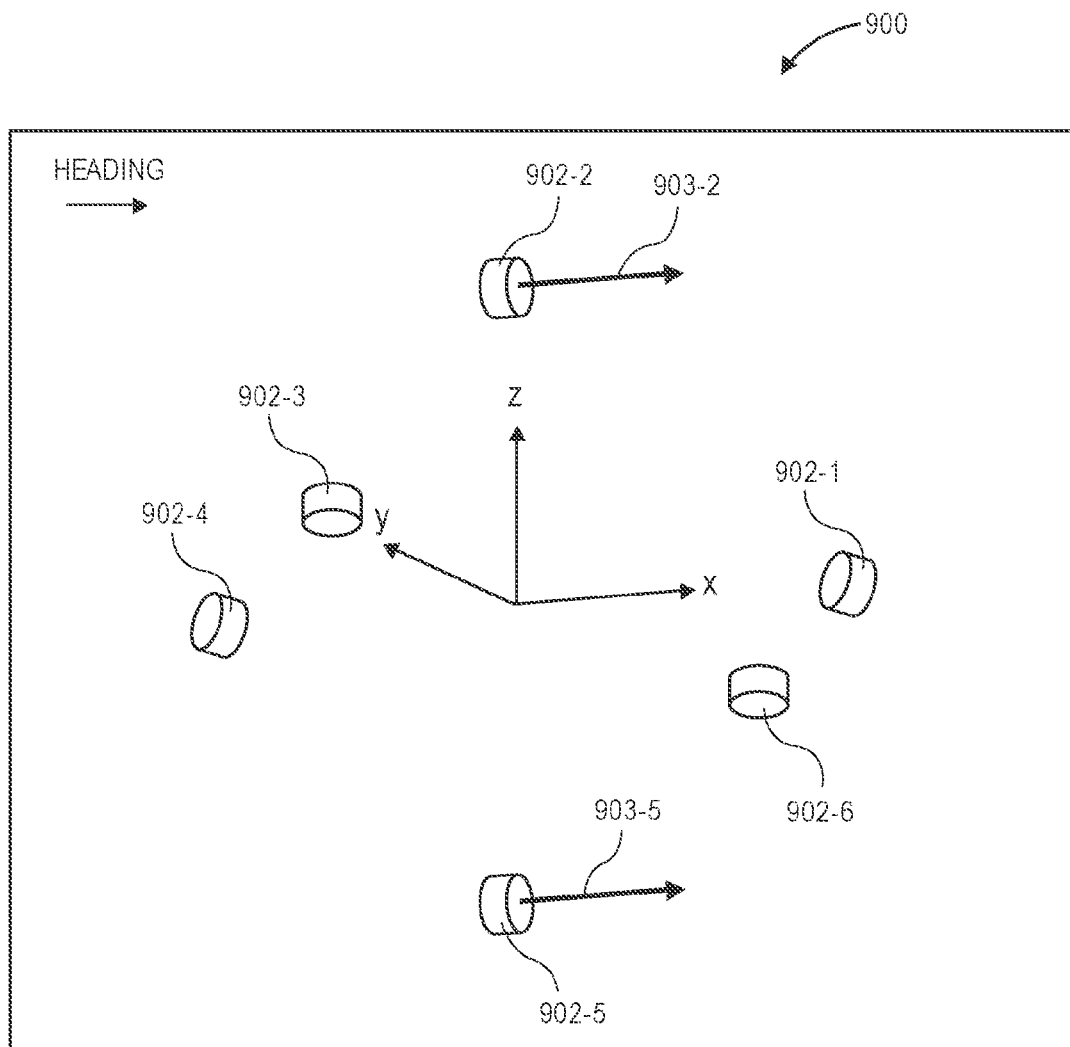


FIG. 9

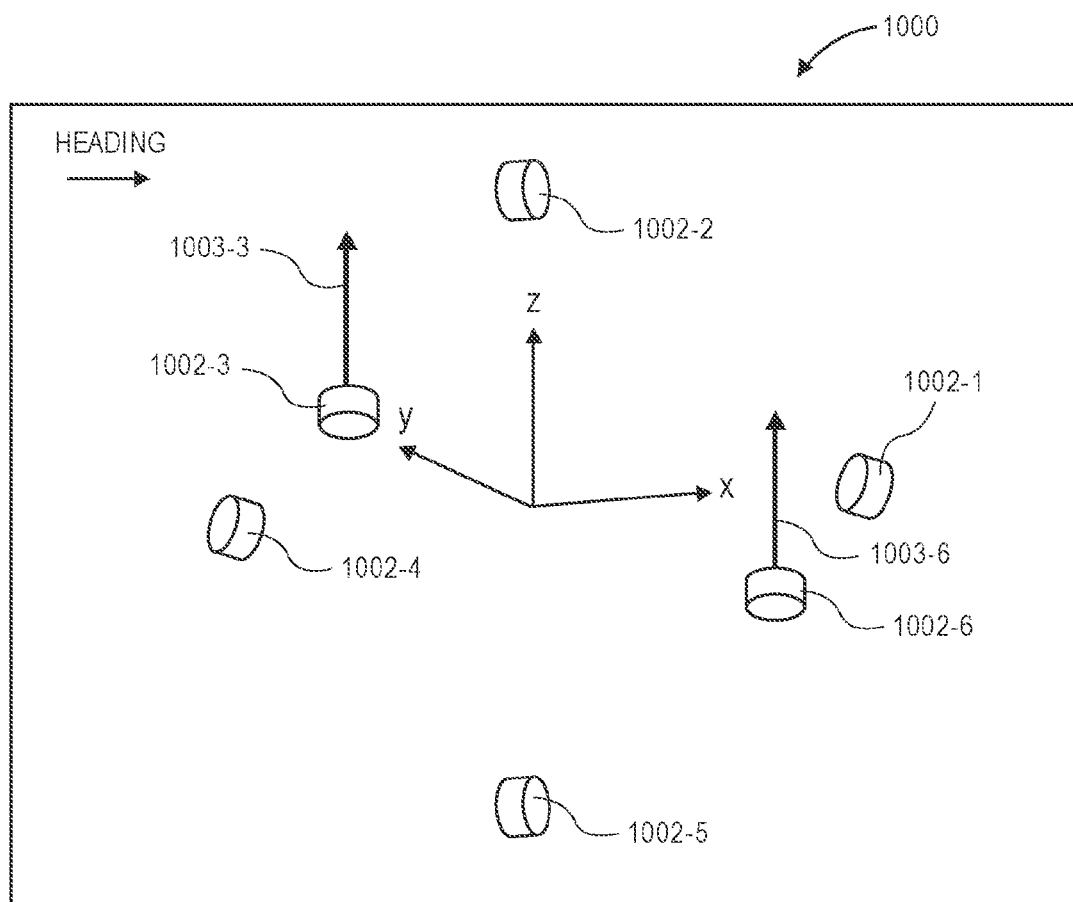


FIG. 10

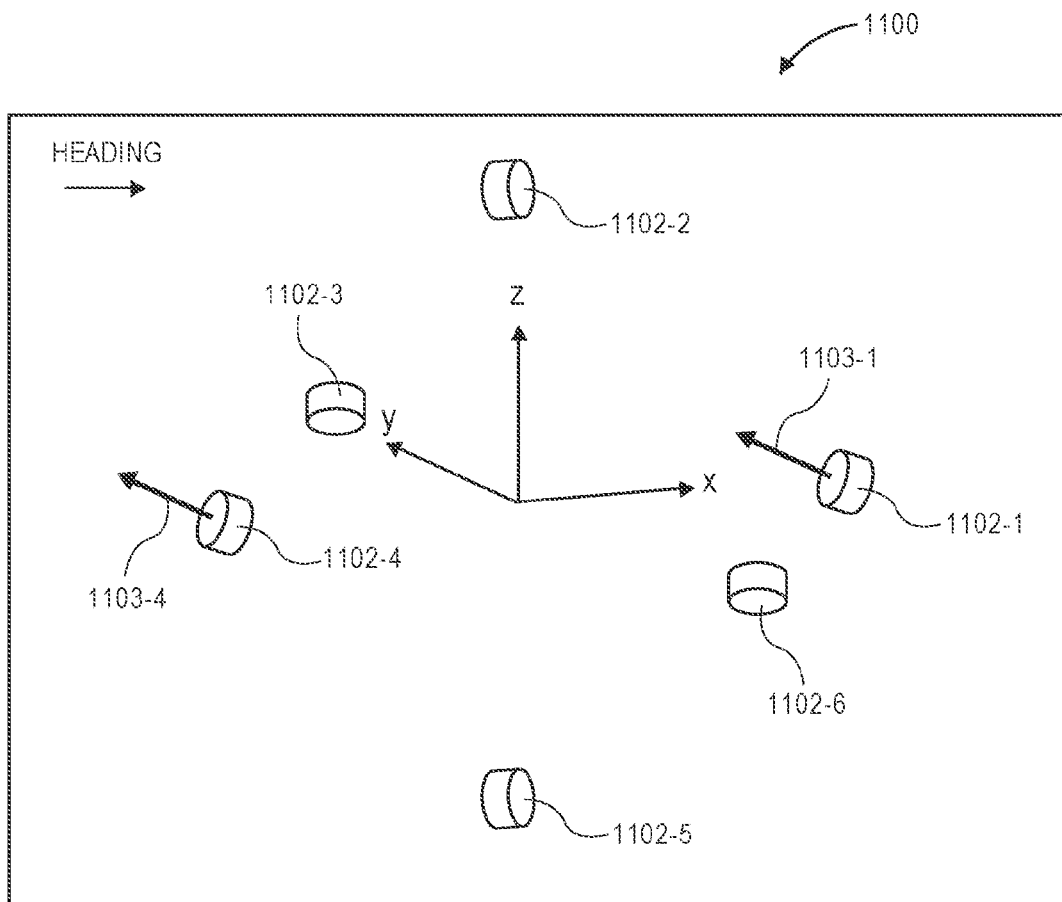


FIG. 11

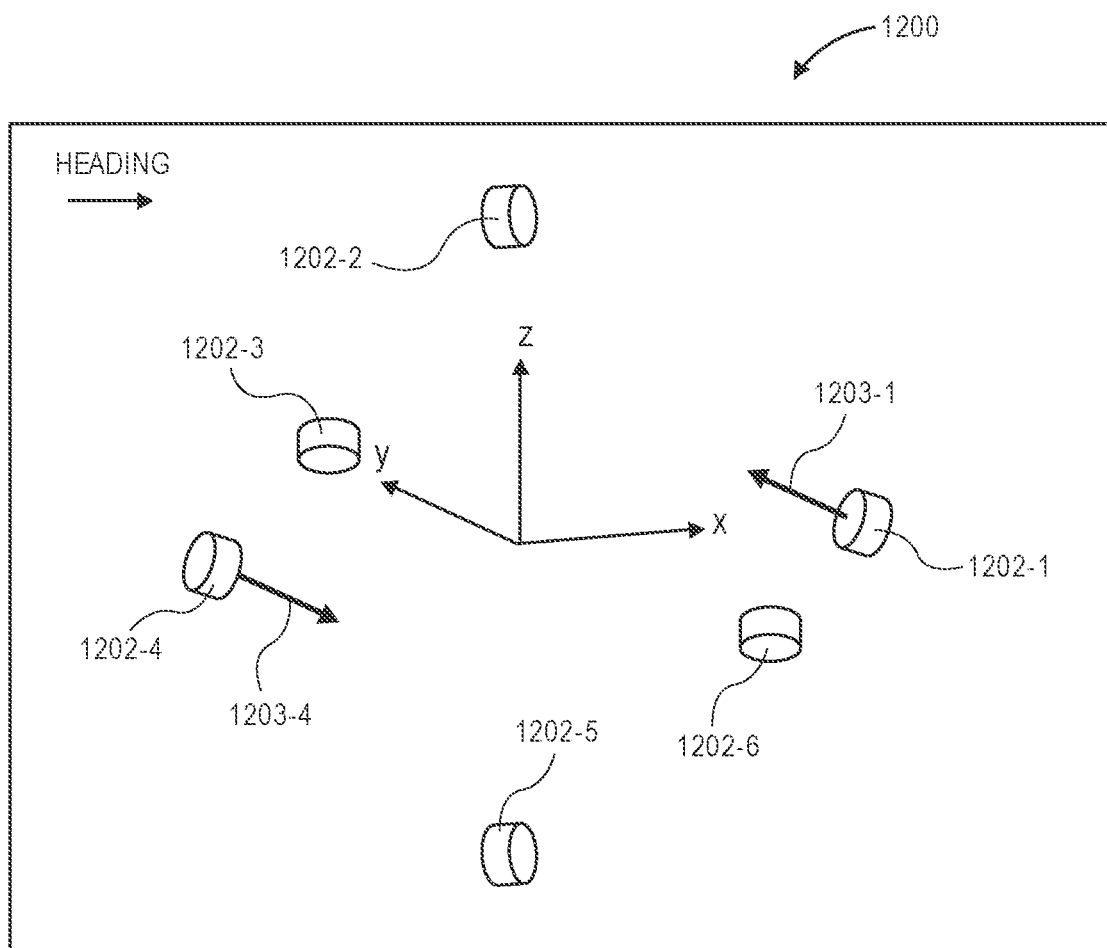


FIG. 12

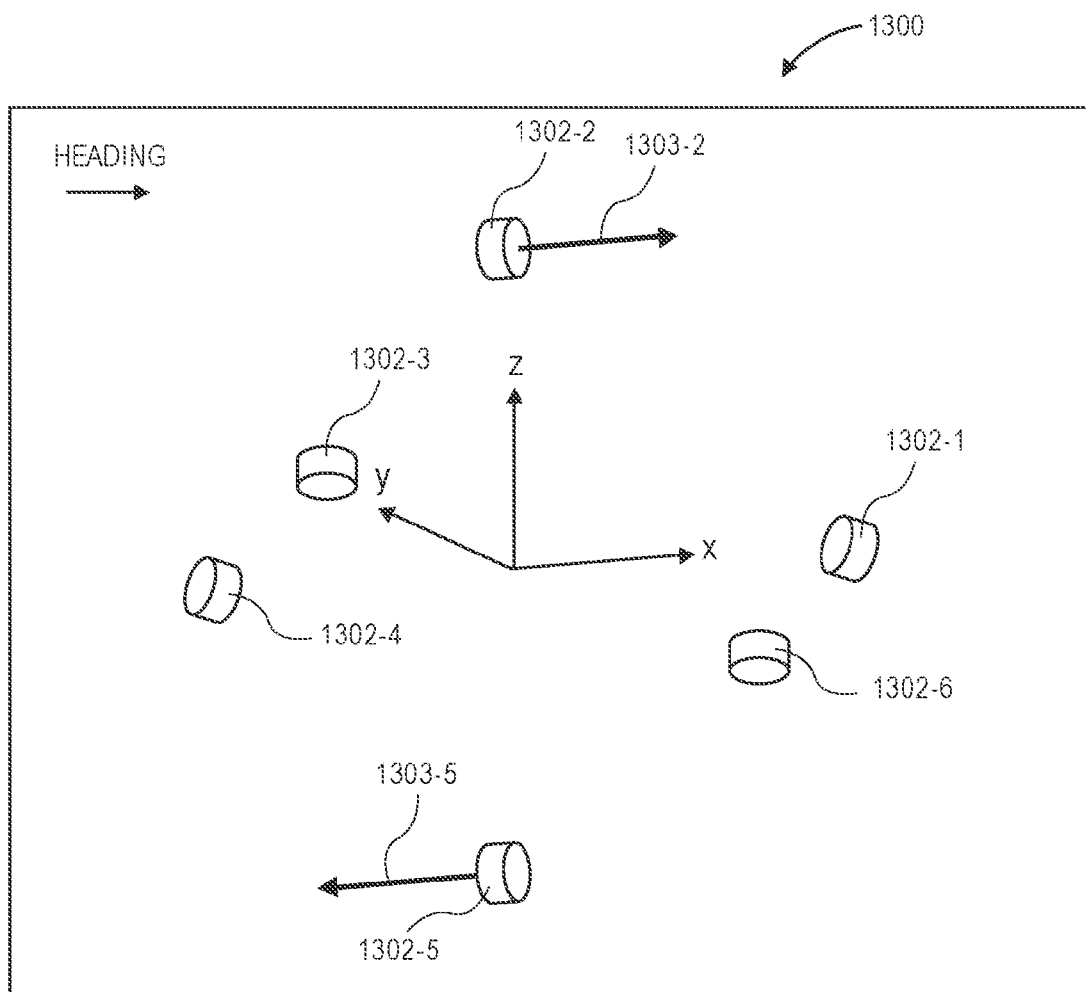


FIG. 13

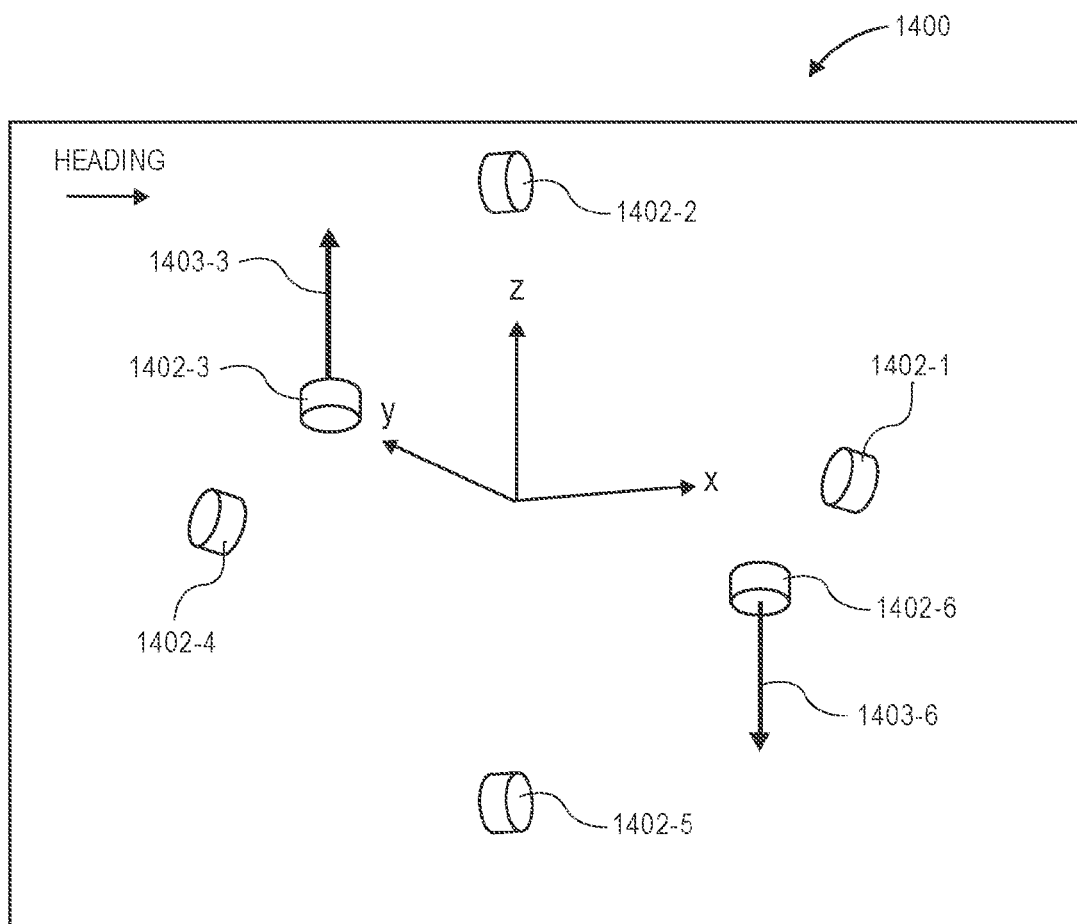
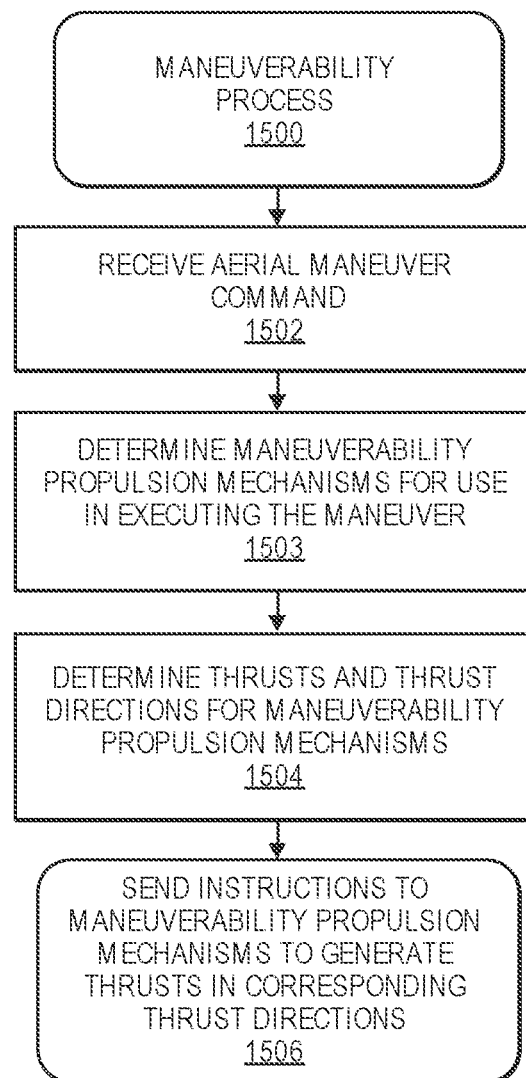
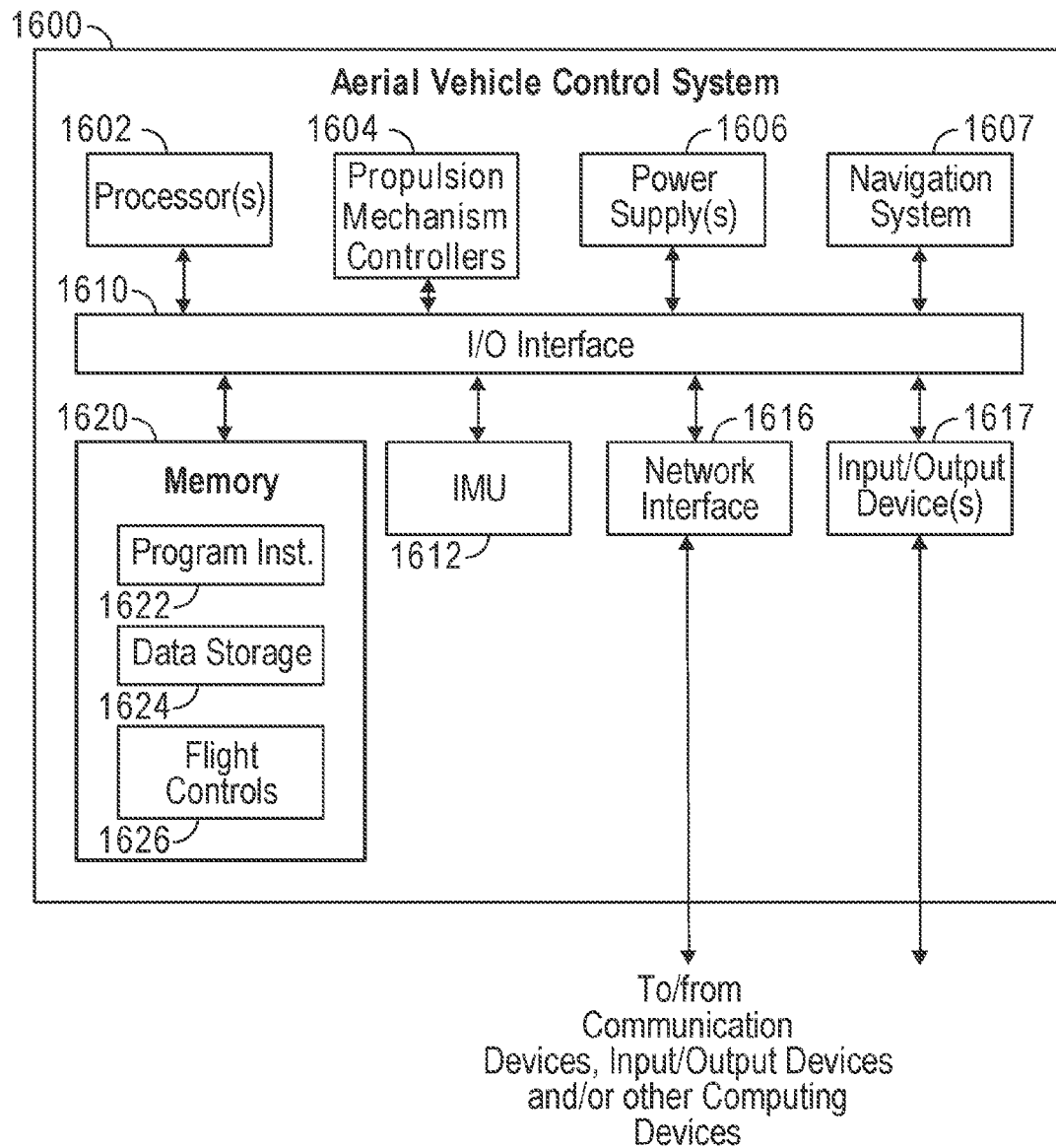


FIG. 14

**FIG. 15**

**FIG. 16**

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SIX DEGREE OF FREEDOM AERIAL VEHICLE

BACKGROUND

Unmanned aerial vehicles (“UAV”), such as aerial, ground and water based automated vehicles, are continuing to increase in use. For example, UAVs are often used by hobbyists to obtain aerial images of buildings, landscapes, etc. Likewise, unmanned ground based units are often used in materials handling facilities to autonomously transport inventory within the facility. While there are many beneficial uses of these vehicles, they also have many drawbacks. For example, due to current design limitations, unmanned aerial vehicles are typically designed for either agility or efficiency, but not both. Likewise, aerial vehicles are designed to only operate with four degrees of freedom—pitch, yaw, roll, and heave.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number appears.

FIG. 1 depicts a diagram of an aerial vehicle, according to an implementation.

FIG. 2 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to surge in the X direction, according to an implementation.

FIG. 3 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to sway in the Y direction, according to an implementation.

FIG. 4 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to heave in the Z direction, according to an implementation.

FIG. 5 is a diagram of the propulsion mechanism of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to pitch, according to an implementation.

FIG. 6 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to yaw, according to an implementation.

FIG. 7 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to roll, according to an implementation.

FIG. 8 depicts a diagram of an aerial vehicle, according to an implementation.

FIG. 9 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to surge in the X direction, according to an implementation.

FIG. 10 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to heave in the Z direction, according to an implementation.

FIG. 11 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to sway in the Y direction, according to an implementation.

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FIG. 12 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to yaw, according to an implementation.

FIG. 13 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to pitch, according to an implementation.

FIG. 14 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to roll, according to an implementation.

FIG. 15 is a flow diagram illustrating an example maneuverability process, according to an implementation.

FIG. 16 is a block diagram illustrating various components of an unmanned aerial vehicle control system, according to an implementation.

While implementations are described herein by way of example, those skilled in the art will recognize that the implementations are not limited to the examples or drawings described. It should be understood that the drawings and detailed description thereto are not intended to limit implementations to the particular form disclosed but, on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope as defined by the appended claims. The headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description or the claims. As used throughout this application, the word “may” is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). Similarly, the words “include,” “including,” and “includes” mean including, but not limited to. Additionally, as used herein, the term “coupled” may refer to two or more components connected together, whether that connection is permanent (e.g., welded) or temporary (e.g., bolted), direct or indirect (e.g., through an intermediary), mechanical, chemical, optical, or electrical. Furthermore, as used herein, “horizontal” flight refers to flight traveling in a direction substantially parallel to the ground (e.g., sea level), and that “vertical” flight refers to flight traveling substantially radially outward from the earth’s center. It should be understood by those having ordinary skill that trajectories may include components of both “horizontal” and “vertical” flight vectors.

DETAILED DESCRIPTION

This disclosure describes aerial vehicles, such as UAVs (e.g., quad-copters, hex-copters, hepta-copters, octa-copters) that operate with six degrees of freedom. Specifically, as described herein, the aerial vehicles may efficiently rotate in any of the three degrees of freedom rotation (pitch, yaw, and roll) and/or any of the three degrees of freedom translation (surge, heave, and sway). For example, the aerial vehicle may include six maneuverability propulsion mechanisms that can be independently activated to cause the aerial vehicle to move in any one or more of the six degrees of freedom. Likewise, in some implementations, the aerial vehicle may include a lifting propulsion mechanism that may be used to generate a lifting force sufficient to lift the aerial vehicle and any attached payload.

The lifting propulsion mechanism increases the efficiency of the aerial vehicle and allows the maneuverability propulsion mechanisms to operate in a wider range of rotational speeds to maneuver the aerial vehicle. For example, the lifting propulsion mechanism may be larger in size than the maneuverability propulsion mechanisms and selected based

on the mass of the aerial vehicle and any anticipated payload. In one implementation, the lifting propulsion mechanism may be selected such that the lifting propulsion mechanism is operating within its most efficient range when generating a force that is approximately equal to and opposite the gravitational force applied to the aerial vehicle.

The lifting motors may be designed with larger, more efficient motors than the maneuverability motors, and the lifting propellers may have a larger diameter than the maneuverability propellers. The lifting motors and lifting propellers provide a primary purpose of providing lift and power efficiency to the aerial vehicle. For example, the lifting motors and lifting propellers may be positioned toward the center of the body of the aerial vehicle and/or at an approximate center of gravity of the aerial vehicle.

In comparison, the maneuverability motors may be configured with smaller, more agile motors, and the maneuverability propellers may be smaller propellers designed for providing high agility and maneuverability for the aerial vehicle. The maneuverability motors provide a primary purpose of maneuvering the aerial vehicle and providing high agility when needed.

During transport, aerial vehicles often must maneuver to change course, avoid obstacles, navigate, ascend, descend, etc. For example, when an aerial vehicle is landing, taking off, or in an area with many objects (e.g., a dense area such as a neighborhood, street, etc.), the aerial vehicle must maneuver as it aerially navigates through the area. Current aerial vehicles, such as quad-copters or octa-copters, are restrained to four degrees of freedom (pitch, yaw, roll, and heave). If the aerial vehicle is commanded to surge and/or sway, it must utilize one or more of the four degrees (pitch, yaw, roll, and heave) to perform the commanded maneuver. For example, if the aerial vehicle is commanded to surge forward, the aerial vehicle must pitch forward so that the thrust from the propulsion mechanisms provide both lift and thrust to propel the aerial vehicle forward.

The propulsion mechanisms described herein, in addition to being able to lift the aerial vehicle and cause the aerial vehicle to move in any of the six degrees of freedom, enable the aerial vehicle to be aerially navigated in any direction and with any orientation.

As used herein, a “materials handling facility” may include, but is not limited to, warehouses, distribution centers, cross-docking facilities, order fulfillment facilities, packaging facilities, shipping facilities, rental facilities, libraries, retail stores, wholesale stores, museums, or other facilities or combinations of facilities for performing one or more functions of materials (inventory) handling. A “delivery location,” as used herein, refers to any location at which one or more inventory items (also referred to herein as a payload) may be delivered. For example, the delivery location may be a person’s residence, a place of business, a location within a materials handling facility (e.g., packing station, inventory storage), or any location where a user or inventory is located, etc. Inventory or items may be any physical goods that can be transported using an aerial vehicle.

FIG. 1 illustrates a view of an aerial vehicle 100, according to an implementation. The aerial vehicle 100 includes six maneuverability motors 101-1, 101-2, 101-3, 101-4, 101-5, and 101-6 and corresponding maneuverability propellers 104-1, 104-2, 104-3, 104-4, 104-5, and 104-6 spaced about the body of the aerial vehicle 100. The propellers 104 may be any form of propeller (e.g., graphite, carbon fiber) and of any size. For example, the maneuverability propellers may be 10 inch-12 inch diameter carbon fiber propellers.

The form and/or size of some of the maneuverability propellers may be different than other maneuverability propellers. Likewise, the maneuverability motors 101 may be any form of motor, such as a direct current (“DC”) brushless motor, and may be of a size sufficient to rotate the corresponding maneuverability propeller. Likewise, in some implementations, the size and/or type of some of the maneuverability motors 101 may be different than other maneuverability motors 101. In some implementations, the maneuverability motors may be rotated in either direction such that the force generated by the maneuverability propellers may be either a positive force, when rotating in a first direction, or a negative force, when rotating in the second direction. Alternatively, or in addition thereto, the pitch of the blades of a maneuverability propeller may be variable. By varying the pitch of the blades, the force generated by the maneuverability propeller may be altered to either be in a positive direction or a negative direction.

Each pair of maneuverability motors 101 and corresponding maneuverability propeller will be referred to herein collectively as a maneuverability propulsion mechanism 102, such as maneuverability propulsion mechanisms 102-1, 102-2, 102-3, 102-4, 102-5, and 102-6. Likewise, while the example illustrated in FIG. 1 describes the maneuverability propulsion mechanisms 102 as including maneuverability motors 101 and maneuverability propellers 104, in other implementations, other forms of propulsion may be utilized as the maneuverability propulsion mechanisms 102. For example, one or more of the maneuverability propulsion mechanisms 102 of the aerial vehicle 100 may utilize fans, jets, turbojets, turbo fans, jet engines, and/or the like to maneuver the aerial vehicle. Generally described, a maneuverability propulsion mechanism 102, as used herein, includes any form of propulsion mechanism that is capable of generating a force sufficient to maneuver the aerial vehicle, alone and/or in combination with other propulsion mechanisms. Furthermore, in selected implementations, propulsion mechanisms (e.g., 102-1, 102-2, 102-3, 102-4, 102-5, and 102-6) may be configured such that their individual orientations may be dynamically modified (e.g., change from vertical to horizontal orientation). For example, if the aerial vehicle is navigating in a horizontal direction, one or more of the propulsion mechanisms 102-1, 102-3, 102-5 may alter orientation to provide horizontal thrust to propel the aerial vehicle horizontally. Likewise, one or more of the propulsion mechanisms may be oriented in other directions to provide thrust for other navigation maneuvers.

Likewise, while the examples herein describe the propulsion mechanisms being able to generate force in either direction, in some implementations, the maneuverability mechanisms may only generate force in a single direction. However, the orientation of the maneuverability mechanism may be adjusted so that the force can be oriented in a positive direction, a negative direction, and/or any other direction.

As illustrated, the maneuverability propulsion mechanisms 102 may be oriented at different angles. As illustrated in FIG. 1, maneuverability propulsion mechanisms 102-1, 102-3, and 102-5 are oriented in approximately the same direction as the lifting propulsion mechanism such that forces generated by each of the maneuverability propulsion mechanisms 102-1, 102-3, 102-5 are approximately parallel to forces generated by the lifting propulsion mechanism. Maneuverability propulsion mechanisms 102-2, 102-4, and 102-6 are oriented at approximately perpendicular to the lifting propulsion mechanism so that forces generated by the maneuverability propulsion mechanisms 102-2, 102-4,

102-6 are approximately perpendicular to forces generated by the lifting propulsion mechanism and the maneuverability propulsion mechanisms **102-1**, **102-3**, and **102-5**.

For ease of discussion, maneuverability propulsion mechanisms that are aligned such that they generate forces that are approximately parallel with forces generated by the lifting propulsion mechanism will be referred to as vertically aligned maneuverability propulsion mechanisms. Maneuverability propulsion mechanisms that are aligned such that they generate forces that are approximately perpendicular to forces generated by the lifting propulsion mechanism will be referred to herein as horizontally aligned maneuverability propulsion mechanisms.

In this example, each of the maneuverability propulsion mechanisms **102** are positioned in approximately the same plane, in this example the X-Y plane, and spaced approximately sixty degrees from each other, such that the maneuverability propulsion mechanisms **102** are positioned at approximately equal distances with respect to one another and around the perimeter of the aerial vehicle **100**. However, in other implementations, the spacing between the maneuverability propulsion mechanisms may be different. For example, the vertically aligned maneuverability propulsion mechanisms **102-1**, **102-3**, and **102-5** may each be approximately equally spaced 120 degrees apart and each of the horizontally aligned maneuverability propulsion mechanisms **102-2**, **102-4**, and **102-6** may also be approximately equally spaced 120 degrees apart. However, the spacing between the vertically aligned maneuverability propulsion mechanisms and the horizontally aligned maneuverability propulsion mechanisms may not be equal. For example, the vertically aligned maneuverability propulsion mechanisms **102-1**, **102-3**, and **102-5** may be positioned at approximately zero degrees, approximately 120 degrees, and approximately 240 degrees, and the horizontally aligned maneuverability propulsion mechanisms may be positioned at approximately 10 degrees, approximately 130 degrees, and approximately 250 degrees.

In other implementations, the maneuverability propulsion mechanisms may have other alignments. Likewise, in other implementations, there may be fewer or additional vertically aligned maneuverability propulsion mechanisms and/or fewer or additional horizontally aligned maneuverability propulsion mechanisms.

In addition to the maneuverability propulsion mechanisms **102**, the aerial vehicle **100** may also include one or more lifting motors **108** and corresponding lifting propellers **106**. The lifting motor and corresponding lifting propeller are of a size and configuration to generate a force that will lift the aerial vehicle and any engaged payload such that the aerial vehicle can aurally navigate. For example, the lifting propeller may be a 29 inch-32 inch diameter carbon fiber propeller.

In some implementations, the lifting motor **108** and corresponding lifting propeller **106** may be sized such that they are capable of generating a force that is approximately equal and opposite to the gravitational force applied to the aerial vehicle **100**. For example, if the mass of the aerial vehicle, without a payload, is 20.00 kilograms (kg), the gravitational force acting on the aerial vehicle is 196.20 Newtons (N). If the aerial vehicle is designed to carry a payload having a mass between 0.00 kg and 8.00 kg, the lifting motor and lifting propeller may be selected such that, when generating a force between 196.00 N and 275.00 N, the lifting motor is operating in its most power efficient range.

Additional information regarding aerial vehicles that include a lifting propeller, lifting motor, maneuverability propellers, and maneuverability motors can be found in co-pending U.S. patent application Ser. No. 14/611,983, filed Feb. 2, 2015, and titled "MANEUVERING AN UNMANNED AERIAL VEHICLE WITHOUT CONSIDERING THE EFFECTS OF GRAVITY," the contents of which are herein incorporated by reference in their entirety.

Each lifting motor **108** and corresponding lifting propeller **106** will be referred to herein collectively as a lifting propulsion mechanism. Likewise, while the example illustrated in FIG. 1 describes the lifting propulsion mechanism as including a lifting motor **108** and lifting propeller **106**, in other implementations, other forms of propulsion may be utilized as the lifting propulsion mechanisms. For example, one or more of the lifting propulsion mechanisms of the aerial vehicle may utilize fans, jets, turbojets, turbo fans, jet engines, and/or the like to lift the aerial vehicle. Generally described, a lifting propulsion mechanism, as used herein, includes any form of propulsion mechanism that is capable of generating a force sufficient to lift the aerial vehicle and any attached payload, alone and/or in combination with other propulsion mechanisms.

To counteract the angle of momentum of the lifting propeller **106**, one or more of the maneuverability propellers **104** may rotate in a direction opposite that of the lifting propeller **106** to keep the aerial vehicle **100** from rotating with the rotation of the lifting propeller **106**.

The body or housing of the aerial vehicle **100** may likewise be of any suitable material, such as graphite, carbon fiber, and/or aluminum. In this example, the body of the aerial vehicle **100** includes a perimeter shroud **110** that surrounds the lifting propeller **106** and six arms **105-1**, **105-2**, **105-3**, **105-4**, **105-5**, and **105-6** that extend radially from a central portion of the aerial vehicle. In this example, each of the arms are coupled to and form the central portion and the lifting motor **108** is also mounted to the central portion. Coupled to the opposing ends of the arms **105-1**, **105-2**, **105-3**, **105-4**, **105-5**, and **105-6** are the maneuverability propulsion mechanisms **102**, discussed above. Also, as discussed above, the spacing between the different maneuverability propulsion mechanisms may be altered by altering a position of one or more of the arms **105** extending from the central portion of the aerial vehicle **100**.

While the implementation illustrated in FIG. 1 includes six arms **105** that extend radially from a central portion of the aerial vehicle **100** to form the frame or body of the aerial vehicle, in other implementations, there may be fewer or additional arms. For example, the aerial vehicle may include support arms that extend between the arms **105** and provide additional support to the aerial vehicle and/or to support the payload engagement mechanism **112**. The arms **105**, shroud **110**, and/or payload engagement mechanism **112** of the aerial vehicle may be formed of any type of material, including, but not limited to, graphite, carbon fiber, aluminum, titanium, Kevlar, etc.

As discussed, in the illustrated configuration of the aerial vehicle **100**, three of the maneuverability propulsion mechanisms **102-1**, **102-3**, and **102-5** are vertically aligned and three of the maneuverability propulsion mechanisms **102-2**, **102-4**, and **102-6** are horizontally aligned. With such a configuration, the aerial vehicle **100** can be aurally navigated in any direction and with any orientation.

For example, the aerial vehicle **100** may navigate with the heading and direction described with respect to FIGS. 2-7 in which the maneuverability propulsion mechanism **102-6** is indicated as being in the direction of the heading and the

aerial vehicle **100** oriented such that the lifting propulsion mechanism and maneuverability propulsion mechanisms **102-1**, **102-3**, and **102-5** are oriented to generate vertical forces that are opposite the gravitational force acting on the aerial vehicle. However, in other implementations, the aerial vehicle may be aerially navigated with any other heading. Likewise, the aerial vehicle may have any orientation. For example, the aerial vehicle could be vertically oriented such that the lifting propulsion mechanism is aligned substantially perpendicular to the force of gravity acting on the vehicle. In such an orientation, the lifting propulsion mechanism and/or the maneuverability propulsion mechanisms **102-1**, **102-3**, and **102-5**, when generating forces, will generate forces that are approximately perpendicular to the force of gravity acting on the aerial vehicle **100**. Likewise, the maneuverability propulsion mechanisms **102-2**, **102-4**, and **102-6** may be used to generate forces that are opposite the force of gravity acting on the vehicle to maintain an altitude of the aerial vehicle. At other orientations, one or more combinations of the lifting propulsion mechanism and/or the maneuverability propulsion mechanisms may be used to generate lifting forces to maintain the aerial vehicle at an altitude and to generate other forces to aerially maneuver the aerial vehicle **100**.

In some implementations, the payload engagement mechanism **112** may be coupled to one or more of the arms **105** and be configured to selectively engage and/or disengage a payload. Also coupled to and/or included within one or more of the arms **105** is an aerial vehicle control system **111** and one or more power modules **118**, such as a battery. In this example, the aerial vehicle control system **111** is mounted inside arm **105-5** and the power module **118** is mounted to the arm **105-3**. The aerial vehicle control system **111**, as discussed in further detail below with respect to FIG. **16**, controls the operation, routing, navigation, communication, lifting motor control, maneuverability motor controls, and/or the payload engagement mechanism **112** of the aerial vehicle **100**.

The power module(s) **118** may be removably mounted to the aerial vehicle **100**. The power module(s) **118** for the aerial vehicle may be in the form of battery power, solar power, gas power, super capacitor, fuel cell, alternative power generation source, or a combination thereof. The power module(s) **118** are coupled to and provide power for the aerial vehicle control system **111**, the propulsion mechanisms, and the payload engagement mechanism.

In some implementations, one or more of the power modules may be configured such that it can be autonomously removed and/or replaced with another power module. For example, when the aerial vehicle lands at a delivery location, relay location and/or materials handling facility, the aerial vehicle may engage with a charging member at the location that will recharge the power module.

As mentioned above, the aerial vehicle **100** may also include a payload engagement mechanism **112**. The payload engagement mechanism may be configured to engage and disengage items and/or containers that hold items. In this example, the payload engagement mechanism is positioned beneath the body of the aerial vehicle **100**. The payload engagement mechanism **112** may be of any size sufficient to securely engage and disengage items and/or containers that contain items. In other implementations, the payload engagement mechanism may operate as the container, containing the item(s). The payload engagement mechanism communicates with (via wired or wireless communication) and is controlled by the aerial vehicle control system **111**.

FIGS. **2-7** are diagrams of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. **1**. To aid in explanation, other components of the aerial vehicle have been omitted from FIGS. **2-7** and different forces that may be generated by one or more of the maneuverability propulsion mechanisms are illustrated by vectors. The illustrated forces, when generated, will cause the aerial vehicle to surge (FIG. **2**), sway (FIG. **3**), heave (FIG. **4**), pitch (FIG. **5**), yaw (FIG. **6**), and roll (FIG. **7**). In addition to the forces generated by one or more of the maneuverability propulsion mechanisms, the aerial vehicle may be lifted by forces generated by the lifting propulsion mechanism discussed above and illustrated in FIG. **1**. For example, the lifting propulsion mechanism may be used to generate a force that is approximately equal to and opposite the force acting upon the aerial vehicle due to gravity so that the aerial vehicle will remain at a given altitude. The maneuverability propulsion mechanisms may then be used, as discussed, to cause the aerial vehicle to move in one or more of the six degrees of freedom.

FIG. **2** is a diagram of the maneuverability propulsion mechanisms **202** of the aerial vehicle illustrated in FIG. **1** with thrust vectors **203** to cause the aerial vehicle to surge in the X direction, according to an implementation. The maneuverability propulsion mechanisms **202** illustrated in FIG. **2** correspond to the maneuverability propulsion mechanisms illustrated in FIG. **1**. As discussed above, each of the maneuverability propulsion mechanisms **202** are approximately in the same plane, in this example, the X-Y plane. Likewise, while the aerial vehicle may navigate in any direction, FIG. **2** indicates a heading of the aerial vehicle **200**.

In the configuration of the aerial vehicle **200**, to cause the aerial vehicle **200** to surge in the X direction, horizontally aligned maneuverability propulsion mechanisms **202-2** and **202-4** generate forces that are approximately equal in magnitude. Each of the forces **203-2** and **203-4** have an X component and a Y component. The Y components of the forces **203-2** and **203-4** cancel each other out and the X components of the forces **203-2** and **203-4** combine to cause the aerial vehicle **200** to surge in the X direction consistent with the heading of the aerial vehicle **200**.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **202-1**, **202-3**, **202-5**, and **202-6** may not generate any force. If other movements are commanded in addition to a surge in the X direction, one or more of the other maneuverability propulsion mechanisms **202** may likewise generate a force and/or one of the forces **203-2** or **203-4** may be greater or less, thereby causing the aerial vehicle to yaw about the Z axis.

FIG. **3** is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. **1** with thrust vectors to cause the aerial vehicle to sway in the Y direction, according to an implementation. The maneuverability propulsion mechanisms **302** illustrated in FIG. **3** correspond to the maneuverability propulsion mechanisms illustrated in FIG. **1**. As discussed above, each of the maneuverability propulsion mechanisms **302** are approximately in the same plane, in this example, the X-Y plane. Likewise, while the aerial vehicle may navigate in any direction, FIG. **3** indicates a heading of the aerial vehicle **300**.

In the configuration of the aerial vehicle **300**, to cause the aerial vehicle **300** to sway in the Y direction, horizontally aligned maneuverability propulsion mechanism **302-6** generates a force **303-6** in the Y direction. Likewise, maneuverability propulsion mechanisms **302-2** and **302-4** generate

forces **303-2** and **303-4** that when summed have a combined force in the Y direction with a magnitude that is approximately equal to the magnitude of the force **303-6** generated by the maneuverability propulsion mechanism **302-6**. Each of the forces **303-2** and **303-4** have an X component and a Y component. The X components of the forces **303-2** and **303-4** cancel each other out and the Y component of the forces **303-2** and **303-4** combine and equal the Y component of the force **303-6** to cause the aerial vehicle **300** to sway in the Y direction.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **302-1**, **302-3**, and **302-5** may not generate any force. If other movements are commanded in addition to a sway in the Y direction, one more of the other maneuverability propulsion mechanisms **302** may likewise generate a force and/or one of the forces **303-2**, **303-4**, and/or **303-6** may be greater or less, thereby causing the aerial vehicle to yaw about the Z axis.

FIG. 4 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to heave in the Z direction, according to an implementation. The maneuverability propulsion mechanisms **402** illustrated in FIG. 4 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 1. As discussed above, each of the maneuverability propulsion mechanisms **402** are approximately in the same plane, in this example, the X-Y plane. Likewise, while the aerial vehicle may navigate in any direction, FIG. 4 indicates a heading of the aerial vehicle **400**.

In the configuration of the aerial vehicle **400**, to cause the aerial vehicle **400** to heave in the Z direction, vertically aligned maneuverability propulsion mechanisms **402-1**, **402-3**, and **402-5** generate forces **403-1**, **403-3**, and **403-5** that are approximately equal and in the Z direction. Because each of the maneuverability propulsion mechanisms are vertically aligned, as discussed above, the generated forces only have a Z component.

Causing the aerial vehicle to heave in the Z direction may be used, for example, to increase or decrease the altitude of the aerial vehicle that is maintained by the lifting propulsion mechanism. For example, if the lifting propulsion mechanism is generating a force that is approximately equal to and opposite the force of gravity acting on the aerial vehicle **400** and the vertically aligned maneuverability propulsion mechanisms generate a positive vertical force, as illustrated in FIG. 4, the altitude of the aerial vehicle will increase because the total force acting on the vehicle as a result of the lifting propulsion mechanism and the forces **403-1**, **403-3**, and **403-5** are greater than the gravitational force acting on the aerial vehicle. Similarly, if the lifting propulsion mechanism is generating a force that is approximately equal to and opposite the force of gravity acting on the aerial vehicle **400** and the vertically aligned maneuverability propulsion mechanisms **402-1**, **402-3**, and **402-5** generate a negative vertical force, the altitude of the aerial vehicle will decrease because the total force acting on the aerial vehicle as a result of the negative vertical force and the force of gravity acting on the aerial vehicle is greater than the force generated by the lifting propulsion mechanism.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **402-2**, **402-4**, and **402-6** may not generate any force. If other movements are commanded in addition to a heave in the Z direction, one or more of the other maneuverability propulsion mechanisms **402** may likewise generate a force and/or

one of the forces **403-1**, **403-3**, or **403-5** may be greater or less, thereby causing the aerial vehicle to pitch and/or roll.

FIG. 5 is a diagram of the maneuverability propulsion mechanisms **502** of the aerial vehicle illustrated in FIG. 1 with thrust vectors **503** to cause the aerial vehicle to pitch about the Y axis, according to an implementation. The maneuverability propulsion mechanisms **502** illustrated in FIG. 5 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 1. As discussed above, each of the maneuverability propulsion mechanisms **502** are approximately in the same plane, in this example, the X-Y plane. Likewise, while the aerial vehicle may navigate in any direction, FIG. 5 indicates a heading of the aerial vehicle **500**.

In the configuration of the aerial vehicle **500**, to cause the aerial vehicle **500** to pitch such that the portion of the aerial vehicle aligned toward the indicated heading moves in the positive Z direction, vertically aligned maneuverability propulsion mechanisms **502-1**, **502-3**, and **502-5** generate forces in the Z direction. Specifically, maneuverability propulsion mechanisms **502-1** and **502-5** generate vertical forces **503-1** and **503-5** that are approximately equal in magnitude and maneuverability propulsion mechanism **502-3** generates a force that is approximately twice the magnitude as either force **503-1** or **503-5**. The forces **503-1** and **503-5** are in the positive Z direction and force **503-3** is in the negative Z direction. Summing the forces **503-1**, **503-3**, and **503-5** results in a rotational force that causes the aerial vehicle to pitch such that the portion of the aerial vehicle aligned toward the heading moves in the positive Z direction.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **502-2**, **502-4**, and **502-6** may not generate any force. If other movements are commanded in addition to a pitch, one more of the other maneuverability propulsion mechanisms **502** may likewise generate a force and/or one of the forces **503-1** or **503-5** may be greater or less, thereby causing the aerial vehicle to roll.

FIG. 6 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to yaw about the Z axis, according to an implementation. The maneuverability propulsion mechanisms **603** illustrated in FIG. 6 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 1. As discussed above, each of the maneuverability propulsion mechanisms **602** are approximately in the same plane, in this example, the X-Y plane. Likewise, while the aerial vehicle may navigate in any direction, FIG. 6 indicates a heading of the aerial vehicle **600**.

In the configuration of the aerial vehicle **600**, to cause the aerial vehicle **600** to yaw, horizontally aligned maneuverability propulsion mechanisms **602-2**, **602-4**, and **602-6** generate forces that are approximately equal in magnitude. The force **603-6** only includes a Y component because of the alignment of the maneuverability propulsion mechanism **602-6**. Forces **603-2** and **603-4** each have an X component and a Y component. However, because of the alignment of the maneuverability propulsion mechanisms **602-2**, **602-4**, the X components of the two forces **603-2**, **603-4** cancel each other out. The resulting forces in the Y direction cause the aerial vehicle **600** to yaw about the Z axis.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **602-1**, **602-3**, and **602-5** may not generate any force. If other movements are commanded in addition to a yaw, one more of the other maneuverability propulsion mechanisms **602** may likewise generate a force and/or one of the forces

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603-2, 603-4, or 603-6 may be greater or less, thereby causing the aerial vehicle to sway and/or surge.

FIG. 7 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 1 with thrust vectors to cause the aerial vehicle to roll about the X axis, according to an implementation. The maneuverability propulsion mechanisms 703 illustrated in FIG. 7 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 1. As discussed above, each of the maneuverability propulsion mechanisms 702 are approximately in the same plane, in this example, the X-Y plane. Likewise, while the aerial vehicle may navigate in any direction, FIG. 7 indicates a heading of the aerial vehicle 700.

In the configuration of the aerial vehicle 700, to cause the aerial vehicle 700 to roll about the X axis, vertically aligned maneuverability propulsion mechanisms 702-1 and 702-5 generate forces 703-1 and 703-5 that are approximately equal in magnitude but opposite in direction. Because the two forces are equal and opposite in the Z direction, the combined forces will cause the aerial vehicle to roll about the X axis.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms 702-2, 702-3, 702-4, and 702-6 may not generate any force. If other movements are commanded in addition to a surge in the X direction, one more of the other maneuverability propulsion mechanisms 702 may likewise generate a force to cause other maneuvers by the aerial vehicle in addition to a roll.

FIG. 8 illustrates a view of an aerial vehicle 800, according to an implementation. The aerial vehicle 800 includes six maneuverability motors 801-1, 801-2, 801-3, 801-4, 801-5, and 801-6 and corresponding maneuverability propellers 804-1, 804-2, 804-3, 804-4, 804-5, and 804-6 spaced about the body of the aerial vehicle 800. The propellers 804 may be any form of propeller (e.g., graphite, carbon fiber) and of any size. For example, the maneuverability propellers may be 10 inch-12 inch diameter carbon fiber propellers.

The form and/or size of some of the maneuverability propellers may be different than other maneuverability propellers. Likewise, the maneuverability motors 801 may be any form of motor, such as a direct current ("DC") brushless motor, and may be of a size sufficient to rotate the corresponding maneuverability propeller. Likewise, in some implementations, the size and/or type of some of the maneuverability motors 801 may be different than other maneuverability motors 801. In some implementations, the maneuverability motors may be rotated in either direction such that the force generated by the maneuverability propellers may be either a positive force, when rotating in a first direction, or a negative force, when rotating in the second direction.

Each pair of maneuverability motor 801 and corresponding maneuverability propeller will be referred to herein collectively as a maneuverability propulsion mechanism 802, such as maneuverability propulsion mechanisms 802-1, 802-2, 802-3, 802-4, 802-5, and 802-6. Likewise, while the example illustrated in FIG. 8 describes the maneuverability propulsion mechanisms 802 as including maneuverability motors 801 and maneuverability propellers 804, in other implementations, other forms of propulsion may be utilized as the maneuverability propulsion mechanisms 802. For example, one or more of the maneuverability propulsion mechanisms 802 of the aerial vehicle 800 may utilize fans, jets, turbojets, turbo fans, jet engines, and/or the like to maneuver the aerial vehicle. Generally described, a maneuverability propulsion mechanism 802, as used herein, includes any form of propulsion mechanism that is capable

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of generating a force sufficient to maneuver the aerial vehicle, alone and/or in combination with other propulsion mechanisms.

Likewise, while the examples herein describe the propulsion mechanisms being able to generate force in either direction, in some implementations, the maneuverability mechanisms may only generate force in a single direction. However, the orientation of the maneuverability mechanism may be adjusted so that the force can be oriented in either a positive direction, negative direction, and/or any other direction.

In comparison to the aerial vehicle discussed above with respect to FIGS. 1-7, the aerial vehicle 800 includes maneuverability propulsion mechanisms 802 that lie in different planes and extend in different directions from the center portion of the aerial vehicle 800. For example, maneuverability propulsion mechanisms 802-1, 802-3, 802-4, and 802-6 lie in the X-Y plane but maneuverability propulsion mechanisms 802-2 and 802-5 lie along the Z axis and outside of the X-Y plane. While the aerial vehicle 800 can be oriented to fly in any direction, for purposes of discussion with respect to FIGS. 8-14, we will refer to the aerial vehicle 800 as having an upper side and a heading. Specifically, the aerial vehicle 800 will be discussed as having a heading in the X direction, as illustrated by the Heading arrows in FIGS. 8-14. Likewise, the aerial vehicle will be discussed as having a top or upper side that corresponds to the Z axis. Specifically, the aerial vehicle will be described with respect to FIGS. 8-14 in a manner such that the maneuverability propulsion mechanism 802-2 will be considered to be on the top or upper side of the aerial vehicle 800 and the maneuverability propulsion mechanism 802-1 will be considered to be in the front of the aerial vehicle 800.

As illustrated, in addition to some of the maneuverability propulsion mechanisms 802 being in different planes, the maneuverability propulsion mechanisms 802 may be oriented at different angles. As illustrated in FIG. 8, maneuverability propulsion mechanisms 802-3 and 802-6 are oriented in approximately the same direction as the lifting propulsion mechanism such that forces generated by each of the maneuverability propulsion mechanisms 802-3 and 802-6 are approximately parallel to forces generated by the lifting propulsion mechanism, which includes the lifting propellers 806. Maneuverability propulsion mechanisms 802-1 and 802-4 are oriented at approximately ninety degrees to the lifting propulsion mechanism so that forces generated by the maneuverability propulsion mechanisms 802-1 and 802-4 are approximately perpendicular to forces generated by the lifting propulsion mechanism and the maneuverability propulsion mechanisms 802-3 and 802-6, but in the same plane. Likewise, maneuverability propulsion mechanisms 802-2 and 802-5 are approximately perpendicular to the lifting propulsion mechanism and approximately perpendicular to the maneuverability propulsion mechanisms 802-1, 802-3, 802-4, and 802-6, and out of the X-Y plane.

For ease of discussion, maneuverability propulsion mechanisms that are aligned such that they generate forces that are approximately parallel with forces generated by the lifting propulsion mechanism will be referred to as vertically aligned maneuverability propulsion mechanisms. Maneuverability propulsion mechanisms that are aligned such that they generate forces that are approximately perpendicular to forces generated by the lifting propulsion mechanism will be referred to herein as horizontally aligned maneuverability propulsion mechanisms.

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In this example, each of the maneuverability propulsion mechanisms **802** are positioned at right angles with respect to one another and extend from a central portion in a cubic manner, with each maneuverability propulsion mechanism positioned on an exterior surface of a six-sided cube, and the lifting propulsion mechanism at a central portion of the cube.

In other implementations, the maneuverability propulsion mechanisms may have other alignments. Likewise, in other implementations, there may be fewer or additional vertically aligned maneuverability propulsion mechanisms and/or fewer or additional vertically aligned maneuverability propulsion mechanisms.

In addition to the maneuverability propulsion mechanisms **802**, the aerial vehicle **800** may also include one or more lifting motors and corresponding lifting propellers **806**. The lifting motor and corresponding lifting propeller are of a size and configuration to generate a force that will lift the aerial vehicle and any engaged payload such that the aerial vehicle can aerally navigate. For example, the lifting propeller may be a 12 inch-22 inch diameter carbon fiber propeller.

In some implementations, the lifting motor and corresponding lifting propeller may be sized such they are capable of generating a force that is approximately equal and opposite to the gravitational force applied to the aerial vehicle **800**. For example, if the mass of the aerial vehicle, without a payload, is 90.00 kilograms (kg), the gravitational force acting on the aerial vehicle is 896.20 Newtons (N). If the aerial vehicle is designed to carry a payload having a mass between 0.00 kg and 8.00 kg, the lifting motor and lifting propeller may be selected such that when generating a force between 896.00 N and 975.00 N, the lifting motor is operating in its most power efficient range.

Each lifting motor and corresponding lifting propeller **806** will be referred to herein collectively as a lifting propulsion mechanism. Likewise, while the example illustrated in FIG. **8** describes the lifting propulsion mechanism as including a lifting motor and lifting propeller **806**, in other implementations, other forms of propulsion may be utilized as the lifting propulsion mechanisms. For example, one or more of the lifting propulsion mechanisms of the aerial vehicle may utilize fans, jets, turbojets, turbo fans, jet engines, and/or the like to lift the aerial vehicle. Generally described, a lifting propulsion mechanism, as used herein, includes any form of propulsion mechanism that is capable of generating a force sufficient to lift the aerial vehicle and any attached payload, alone and/or in combination with other propulsion mechanisms.

To counteract the angle of momentum of the lifting propeller **806**, one or more of the maneuverability propellers **804-6** and/or **804-3** may rotate in a direction opposite that of the lifting propeller **806** to keep the aerial vehicle **800** from rotating with the rotation of the lifting propeller **806**. Alternatively, or in addition thereto, one or more of the maneuverability propulsion mechanisms **802-1** and **802-4** may generate a force that counteracts and cancels out the rotational force generated by the lifting propulsion mechanism.

The body or housing of the aerial vehicle **800** may likewise be of any suitable material, such as graphite, carbon fiber, and/or aluminum. In this example, the body of the aerial vehicle **800** includes a perimeter shroud **810** that surrounds the lifting propeller **806** and six arms **805-1**, **805-2**, **805-3**, **805-4**, **805-5**, and **805-6** that extend at approximately ninety degrees with respect to each other from a central portion of the aerial vehicle **800**. In this example, each of the arms are coupled to and form the

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central portion and the lifting motor is also mounted to the central portion. Coupled to the opposing ends of the arms **805-1**, **805-2**, **805-3**, **805-4**, **805-5**, and **805-6** are the maneuverability propulsion mechanisms **802**, discussed above.

While the implementation illustrated in FIG. **8** includes six arms **805** that extend from a central portion of the aerial vehicle **800** to form the frame or body of the aerial vehicle, in other implementations, there may be fewer or additional arms. For example, the aerial vehicle may include support arms that extend between the arms **805** and provide additional support to the aerial vehicle and/or to support a payload engagement mechanism. The arms **805**, shroud **810**, and/or payload engagement mechanism of the aerial vehicle may be formed of any type of material, including, but not limited to, graphite, carbon fiber, aluminum, titanium, Kevlar, etc.

As discussed, in the illustrated configuration of the aerial vehicle **800**, two of the maneuverability propulsion mechanisms **802-3**, and **802-6** are vertically aligned and four of the maneuverability propulsion mechanisms **802-1**, **802-2**, **802-3**, and **802-5** are horizontally aligned. With such a configuration, the aerial vehicle **800** can be aerally navigated in any direction and with any orientation.

For example, the aerial vehicle **800** may navigate with the heading and direction described with respect to FIGS. **9-14** in which the maneuverability propulsion mechanism **802-1** is indicated as being in the direction of the heading and the aerial vehicle **800** oriented such that maneuverability propulsion mechanism **802-2** is considered to be at the top of the aerial vehicle **800**. However, in other implementations, the aerial vehicle may be aerally navigated with any other heading. Likewise, the aerial vehicle may have any orientation. For example, the aerial vehicle could rotate in any direction oriented such that the lifting propulsion mechanism is aligned substantially perpendicular to the force of gravity acting on the vehicle. In such an orientation, the lifting propulsion mechanism and/or the maneuverability propulsion mechanisms **802-4**, and **802-6**, when generating forces, will generate forces that are approximately perpendicular to the force of gravity acting on the aerial vehicle **800**. Likewise, the maneuverability propulsion mechanisms **802-1**, **802-2**, **802-3**, and **802-5** may be used to generate forces that are opposite the force of gravity acting on the vehicle to maintain an altitude of the aerial vehicle. At other orientations, one or more combinations of the lifting propulsion mechanism and/or the maneuverability propulsion mechanisms may be used to generate lifting forces to maintain the aerial vehicle at an altitude and to generate other forces to aerally maneuver the aerial vehicle **800**.

Coupled to and/or included within one or more of the arms **805** is an aerial vehicle control system **811** and one or more power modules **818**, such as a battery. In this example, the aerial vehicle control system **811** is mounted inside arm **805-2** and the power module is mounted inside arm **805-5**. The aerial vehicle control system **811**, as discussed in further detail below with respect to FIG. **16**, controls the operation, routing, navigation, communication, lifting motor control, maneuverability motor controls, and/or the payload engagement mechanism of the aerial vehicle **800**.

The power module(s) **818** may be removably mounted to the aerial vehicle **800**. The power module(s) **818** for the aerial vehicle may be in the form of battery power, solar power, gas power, super capacitor, fuel cell, alternative power generation source, or a combination thereof. The power module(s) **818** are coupled to and provide power for the aerial vehicle control system **811**, the propulsion mechanisms, and the payload engagement mechanism.

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In some implementations, one or more of the power modules may be configured such that it can be autonomously removed and/or replaced with another power module. For example, when the aerial vehicle lands at a delivery location, relay location and/or materials handling facility, the aerial vehicle may engage with a charging member at the location that will recharge the power module.

FIGS. 9-14 are diagrams of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8. To aid in explanation, other components of the aerial vehicle have been omitted from FIGS. 9-14 and different forces that may be generated by one or more of the maneuverability propulsion mechanisms are illustrated by vectors. The illustrated forces, when generated, will cause the aerial vehicle to surge (FIG. 9), heave (FIG. 10), sway (FIG. 11), yaw (FIG. 12), pitch (FIG. 13), and roll (FIG. 14). The illustrated forces, shown as vectors, are illustrated to show the direction in which the force is acting on the aerial vehicle.

In addition to the forces generated by one or more of the maneuverability propulsion mechanisms, the aerial vehicle may be lifted by forces generated by the lifting propulsion mechanism discussed above and illustrated in FIG. 8. For example, the lifting propulsion mechanism may be used to generate a force that is approximately equal to and opposite the force acting upon the aerial vehicle due to gravity so that the aerial vehicle will remain at an altitude. The maneuverability propulsion mechanisms may then be used, as discussed, to cause the aerial vehicle to move in one or more of the six degrees of freedom.

FIG. 9 is a diagram of the maneuverability propulsion mechanisms 902 of the aerial vehicle illustrated in FIG. 8 with thrust vectors 903 to cause the aerial vehicle to surge in the X direction, according to an implementation. The maneuverability propulsion mechanisms 902 illustrated in FIG. 9 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 8. In this configuration, maneuverability propulsion mechanisms 902-2 and 902-5 are both horizontally aligned and oriented in the same direction such that they can be used to generate either a positive or negative force in the X direction.

In the configuration of the aerial vehicle 900, to cause the aerial vehicle 900 to surge in the X direction, horizontally aligned maneuverability propulsion mechanisms 902-2 and 902-5 generate forces that are approximately equal in magnitude and direction. Because both of the maneuverability propulsion mechanisms are aligned in the X direction, the generated forces 903-2 and 903-5 only have an X component. Those forces 903-2 and 903-5 cause the aerial vehicle 900 to surge in the X direction consistent with the heading of the aerial vehicle 900.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms 902-1, 902-3, 902-4, and 902-6 may not generate any force. If other movements are commanded in addition to a surge in the X direction, one or more of the other maneuverability propulsion mechanisms 902 may likewise generate a force and/or one of the forces 903-2 or 903-5 may be greater or less, thereby causing the aerial vehicle to pitch about the Y axis.

FIG. 10 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to heave in the Z direction, according to an implementation. The maneuverability propulsion mechanisms 1002 illustrated in FIG. 10 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 8. In this configuration, maneuverability propulsion mechanisms 1002-3 and 1002-6 are both verti-

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cally aligned and oriented in the same direction such that they can be used to generate either a positive or negative force in the Z direction.

In the configuration of the aerial vehicle 1000, to cause the aerial vehicle 1000 to heave in the Z direction, vertically aligned maneuverability propulsion mechanisms 1002-3 and 1002-6 generate forces that are approximately equal in magnitude and direction. Because both of the maneuverability propulsion mechanisms are aligned in the Z direction, the generated forces 1003-3 and 1003-6 only have a Z component. Those forces 1003-3 and 1003-6 cause the aerial vehicle 1000 to heave in the Z direction.

Causing the aerial vehicle 1000 to heave in the Z direction may be used, for example, to increase or decrease the altitude of the aerial vehicle that is maintained by the lifting propulsion mechanism discussed above with respect to FIG. 8. For example, if the lifting propulsion mechanism is generating a force that is approximately equal to and opposite the force of gravity acting on the aerial vehicle 1000 and the vertically aligned maneuverability propulsion mechanisms 1002-3 and 1002-6 generate a positive vertical force, as illustrated in FIG. 10, the altitude of the aerial vehicle will increase because the total force acting on the vehicle as a result of the lifting propulsion mechanism and the forces 1003-3, and 1003-6 is greater than the force of gravity acting on the aerial vehicle. Similarly, if the lifting propulsion mechanism is generating a force that is approximately equal to and opposite the force of gravity acting on the aerial vehicle 1000 and the vertically aligned maneuverability propulsion mechanisms 1002-3 and 1002-6 generate a negative vertical force, the altitude of the aerial vehicle will decrease because the total force acting on the aerial vehicle as a result of the negative vertical force from the maneuverability propulsion mechanisms and the force of gravity is greater than the force generated by the lifting propulsion mechanism.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms 1002-1, 1002-2, 1002-4, and 1002-5 may not generate any force. If other movements are commanded in addition to a heave in the Z direction, one or more of the other maneuverability propulsion mechanisms 1002 may likewise generate a force and/or one of the forces 1003-3 or 1003-6 may be greater or less, thereby causing the aerial vehicle to roll about the X axis.

FIG. 11 is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. 8 with thrust vectors to cause the aerial vehicle to sway in the Y direction, according to an implementation. The maneuverability propulsion mechanisms 1103 illustrated in FIG. 11 correspond to the maneuverability propulsion mechanisms illustrated in FIG. 8. Because both of the maneuverability propulsion mechanisms are aligned in the Y direction, the generated forces 1103-1 and 1103-4 only have a Y component. Those forces 1103-1 and 1103-4 cause the aerial vehicle 1100 to sway in the Y direction.

In the configuration of the aerial vehicle 1100, to cause the aerial vehicle 1200 to sway in the Y direction, horizontally aligned maneuverability propulsion mechanisms 1102-1 and 1102-4 generate forces 1103-1 and 1103-4 in the Y direction that are approximately equal in magnitude and direction. Those forces 1103-1 and 1103-4 cause the aerial vehicle 1100 to sway in the Y direction.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms 1102-2, 1102-3, 1102-5, and 1102-6 may not generate any force. If other movements are commanded in addition to a sway in

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the Y direction, one or more of the other maneuverability propulsion mechanisms **1102** may likewise generate a force and/or one of the forces **1103-1** or **1103-4** may be greater or less, thereby causing the aerial vehicle to yaw about the Z axis.

FIG. **12** is a diagram of the maneuverability propulsion mechanisms **1202** of the aerial vehicle illustrated in FIG. **8** with thrust vectors **1203** to cause the aerial vehicle to yaw about the Z axis, according to an implementation. The maneuverability propulsion mechanisms **1202** illustrated in FIG. **12** correspond to the maneuverability propulsion mechanisms illustrated in FIG. **8**. Because both of the maneuverability propulsion mechanisms are aligned, the generated forces **1203-1** and **1203-4** only have a Y component. Those forces **1203-1** and **1203-4** cause the aerial vehicle **1200** to yaw about the Z axis.

In the configuration of the aerial vehicle **1200**, to cause the aerial vehicle **1200** to yaw about the Z axis, horizontally aligned maneuverability propulsion mechanisms **1202-1** and **1202-4** generate forces in the Y direction that are approximately equal in magnitude but opposite in direction. The opposing direction of the forces **1203-1** and **1203-4** cause the aerial vehicle **1200** to yaw about the Z axis.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **1202-2**, **1202-3**, **1202-5**, and **1202-6** may not generate any force. If other movements are commanded in addition to a yaw, one or more of the other maneuverability propulsion mechanisms **1202** may likewise generate a force.

FIG. **13** is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. **8** with thrust vectors to cause the aerial vehicle to pitch about the Y axis, according to an implementation. The maneuverability propulsion mechanisms **1303** illustrated in FIG. **13** correspond to the maneuverability propulsion mechanisms illustrated in FIG. **8**. Because both of the maneuverability propulsion mechanisms **1302-2** and **1302-5** are aligned in the X direction, the generated forces **1303-2** and **1303-5** only have an X component. Those forces **1303-2** and **1303-5** cause the aerial vehicle **1300** to pitch about the Y axis.

In the configuration of the aerial vehicle **1300**, to cause the aerial vehicle **1300** to pitch about the Y axis, horizontally aligned maneuverability propulsion mechanisms **1302-2** and **1302-5** generate forces that are approximately equal in magnitude but opposite in direction. The opposing direction of the forces **1303-2** and **1303-5** cause the aerial vehicle **1300** to pitch downward about the Y axis.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **1302-1**, **1302-3**, **1302-4**, and **1302-6** may not generate any force. If other movements are commanded in addition to a yaw, one or more of the other maneuverability propulsion mechanisms **1302** may likewise generate a force.

FIG. **14** is a diagram of the maneuverability propulsion mechanisms of the aerial vehicle illustrated in FIG. **8** with thrust vectors to cause the aerial vehicle to roll about the X axis, according to an implementation. The maneuverability propulsion mechanisms **1403** illustrated in FIG. **14** correspond to the maneuverability propulsion mechanisms illustrated in FIG. **8**. Because both of the maneuverability propulsion mechanisms **1402-3** and **1402-6** are aligned in the Z direction, the generated forces **1403-3** and **1403-6** only have a Z component. Those forces **1403-3** and **1403-6** cause the aerial vehicle **1400** to roll about the X axis.

In the configuration of the aerial vehicle **1400**, to cause the aerial vehicle **1400** to roll about the X axis, vertically aligned maneuverability propulsion mechanisms **1402-3** and

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1402-6 generate forces **1403-3** and **1403-6** that are approximately equal in magnitude but opposite in direction. Because the two forces are equal in magnitude and opposite in the Z direction, the combined forces will cause the aerial vehicle to roll about the X axis.

If no other movement of the aerial vehicle is commanded, the other maneuverability propulsion mechanisms **1402-1**, **1402-2**, **1402-4**, and **1402-5** may not generate any force. If other movements are commanded in addition to a roll about the X axis, one or more of the other maneuverability propulsion mechanisms **1402** may likewise generate a force to cause other maneuvers by the aerial vehicle in addition to a roll.

FIG. **15** is a flow diagram illustrating an example maneuverability process **1500**, according to an implementation. The example process of FIG. **15** and each of the other processes discussed herein may be implemented in hardware, software, or a combination thereof. In the context of software, the described operations represent computer-executable instructions stored on one or more computer-readable media that, when executed by one or more processors, perform the recited operations. Generally, computer-executable instructions include routines, programs, objects, components, data structures, and the like that perform particular functions or implement particular abstract data types.

The computer-readable media may include non-transitory computer-readable storage media, which may include hard drives, floppy diskettes, optical disks, CD-ROMs, DVDs, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, flash memory, magnetic or optical cards, solid-state memory devices, or other types of storage media suitable for storing electronic instructions. In addition, in some implementations, the computer-readable media may include a transitory computer-readable signal (in compressed or uncompressed form). Examples of computer-readable signals, whether modulated using a carrier or not, include, but are not limited to, signals that a computer system hosting or running a computer program can be configured to access, including signals downloaded through the Internet or other networks. Finally, the order in which the operations are described is not intended to be construed as a limitation, and any number of the described operations can be combined in any order and/or in parallel to implement the routine.

The example maneuverability process **1500** begins by receiving an aerial navigation command that includes a maneuver, as in **1502**. A maneuver may be any command to alter or change an aspect of the aerial vehicle's current flight. For example, a maneuver may be to ascend or descend (heave), increase or decrease speed (surge), move right or left (sway), pitch, yaw, roll, and/or any combination thereof.

Based on the commanded maneuver, the example process determines the maneuverability propulsion mechanisms to be used in executing the maneuver, as in **1503**. As discussed above, the aerial vehicle may include a lifting propulsion mechanism that may be used to generate a lifting force that will maintain the aerial vehicle at an altitude. Likewise, the aerial vehicle may include multiple maneuverability propulsion mechanisms, as discussed above with respect to FIGS. **1-14** that may be selectively used to generate thrusts that will cause the aerial vehicle to execute one or more maneuvers, in any of the six degrees of freedom.

In addition to determining the maneuverability propulsion mechanisms that are to be used to execute the maneuvers, the magnitude and direction of the thrust to be generated by each of the maneuverability propulsion mechanisms is determined, as in **1504**. As discussed above, in some implemen-

tations, the maneuverability propulsion mechanisms may be configured to generate forces in either direction in which they are aligned. Alternatively, or in addition thereto, the maneuverability propulsion mechanisms may be configured such that they are rotatable between two or more positions so that forces generated by the maneuverability propulsion mechanism may be oriented in different directions.

Based on the determined maneuverability propulsion mechanisms that are to be used to generate the commanded maneuvers and the determined magnitudes and directions of the forces to be generated by those maneuverability propulsion mechanisms, instructions are sent to the determined maneuverability propulsion mechanisms that cause the forces to be generated, as in 1506.

FIG. 16 is a block diagram illustrating an example aerial vehicle control system 1600 of the aerial vehicle 100. In various examples, the block diagram may be illustrative of one or more aspects of the aerial vehicle control system 1600 that may be used to implement the various systems and methods discussed herein and/or to control operation of the aerial vehicle 100. In the illustrated implementation, the aerial vehicle control system 1600 includes one or more processors 1602, coupled to a memory, e.g., a non-transitory computer readable storage medium 1620, via an input/output (I/O) interface 1610. The aerial vehicle control system 1600 also includes propulsion mechanism controllers 1604, such as electronic speed controls (ESCs), power supply modules 1606 and/or a navigation system 1607. The aerial vehicle control system 1600 further includes a payload engagement controller 1612, a network interface 1616, and one or more input/output devices 1617.

In various implementations, the aerial vehicle control system 1600 may be a uniprocessor system including one processor 1602, or a multiprocessor system including several processors 1602 (e.g., two, four, eight, or another suitable number). The processor(s) 1602 may be any suitable processor capable of executing instructions. For example, in various implementations, the processor(s) 1602 may be general-purpose or embedded processors implementing any of a variety of instruction set architectures (ISAs), such as the x86, PowerPC, SPARC, or MIPS ISAs, or any other suitable ISA. In multiprocessor systems, each processor(s) 1602 may commonly, but not necessarily, implement the same ISA.

The non-transitory computer readable storage medium 1620 may be configured to store executable instructions, data, flight paths, flight control parameters, center of gravity information, and/or data items accessible by the processor(s) 1602. In various implementations, the non-transitory computer readable storage medium 1620 may be implemented using any suitable memory technology, such as static random access memory (SRAM), synchronous dynamic RAM (SDRAM), nonvolatile/Flash-type memory, or any other type of memory. In the illustrated implementation, program instructions and data implementing desired functions, such as those described herein, are shown stored within the non-transitory computer readable storage medium 1620 as program instructions 1622, data storage 1624 and flight controls 1626, respectively. In other implementations, program instructions, data, and/or flight controls may be received, sent, or stored upon different types of computer-accessible media, such as non-transitory media, or on similar media separate from the non-transitory computer readable storage medium 1620 or the aerial vehicle control system 1600. Generally speaking, a non-transitory, computer readable storage medium may include storage media or memory media such as magnetic or optical media, e.g., disk or

CD/DVD-ROM, coupled to the aerial vehicle control system 1600 via the I/O interface 1610. Program instructions and data stored via a non-transitory computer readable medium may be transmitted by transmission media or signals such as electrical, electromagnetic, or digital signals, which may be conveyed via a communication medium such as a network and/or a wireless link, such as may be implemented via the network interface 1616.

In one implementation, the I/O interface 1610 may be configured to coordinate I/O traffic between the processor(s) 1602, the non-transitory computer readable storage medium 1620, and any peripheral devices, the network interface or other peripheral interfaces, such as input/output devices 1617. In some implementations, the I/O interface 1610 may perform any necessary protocol, timing or other data transformations to convert data signals from one component (e.g., non-transitory computer readable storage medium 1620) into a format suitable for use by another component (e.g., processor(s) 1602). In some implementations, the I/O interface 1610 may include support for devices attached through various types of peripheral buses, such as a variant of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard, for example. In some implementations, the function of the I/O interface 1610 may be split into two or more separate components, such as a north bridge and a south bridge, for example. Also, in some implementations, some or all of the functionality of the I/O interface 1610, such as an interface to the non-transitory computer readable storage medium 1620, may be incorporated directly into the processor(s) 1602.

The propulsion mechanism controllers 1604 communicate with the navigation system 1607 and adjust the rotational speed of each lifting propulsion mechanism and/or the maneuverability propulsion mechanisms to stabilize the aerial vehicle and/or to perform one or more maneuvers and guide the aerial vehicle along a flight path.

The navigation system 1607 may include a global positioning system (GPS), indoor positioning system (IPS), or other similar system and/or sensors that can be used to navigate the aerial vehicle 100 to and/or from a location. The payload engagement controller 1612 communicates with the actuator(s) or motor(s) (e.g., a servo motor) used to engage and/or disengage items.

The network interface 1616 may be configured to allow data to be exchanged between the aerial vehicle control system 1600, other devices attached to a network, such as other computer systems (e.g., remote computing resources), and/or with aerial vehicle control systems of other aerial vehicles. For example, the network interface 1616 may enable wireless communication between the aerial vehicle and an aerial vehicle control system that is implemented on one or more remote computing resources. For wireless communication, an antenna of the aerial vehicle or other communication components may be utilized. As another example, the network interface 1616 may enable wireless communication between numerous aerial vehicles. In various implementations, the network interface 1616 may support communication via wireless general data networks, such as a Wi-Fi network. For example, the network interface 1616 may support communication via telecommunications networks, such as cellular communication networks, satellite networks, and the like.

Input/output devices 1617 may, in some implementations, include one or more displays, imaging devices, thermal sensors, infrared sensors, time of flight sensors, accelerometers, pressure sensors, weather sensors, etc. Multiple input/

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output devices **1617** may be present and controlled by the aerial vehicle control system **1600**. One or more of these sensors may be utilized to assist in landing as well as to avoid obstacles during flight.

As shown in FIG. **16**, the memory may include program instructions **1622**, which may be configured to implement the example routines and/or sub-routines described herein. The data storage **1624** may include various data stores for maintaining data items that may be provided for determining flight paths, landing, identifying locations for disengaging items, determining which maneuver propulsion mechanisms to utilize to execute a maneuver, etc. In various implementations, the parameter values and other data illustrated herein as being included in one or more data stores may be combined with other information not described or may be partitioned differently into more, fewer, or different data structures. In some implementations, data stores may be physically located in one memory or may be distributed among two or more memories.

Those skilled in the art will appreciate that the aerial vehicle control system **1600** is merely illustrative and is not intended to limit the scope of the present disclosure. In particular, the computing system and devices may include any combination of hardware or software that can perform the indicated functions. The aerial vehicle control system **1600** may also be connected to other devices that are not illustrated, or instead may operate as a stand-alone system. In addition, the functionality provided by the illustrated components may, in some implementations, be combined in fewer components or distributed in additional components. Similarly, in some implementations, the functionality of some of the illustrated components may not be provided and/or other additional functionality may be available.

Those skilled in the art will also appreciate that, while various items are illustrated as being stored in memory or storage while being used, these items or portions of them may be transferred between memory and other storage devices for purposes of memory management and data integrity. Alternatively, in other implementations, some or all of the software components may execute in memory on another device and communicate with the illustrated aerial vehicle control system **1600**. Some or all of the system components or data structures may also be stored (e.g., as instructions or structured data) on a non-transitory, computer-accessible medium or a portable article to be read by an appropriate drive, various examples of which are described herein. In some implementations, instructions stored on a computer-accessible medium separate from the aerial vehicle control system **1600** may be transmitted to the aerial vehicle control system **1600** via transmission media or signals such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as a wireless link. Various implementations may further include receiving, sending, or storing instructions and/or data implemented in accordance with the foregoing description upon a computer-accessible medium. Accordingly, the techniques described herein may be practiced with other aerial vehicle control system configurations.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claims.

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What is claimed is:

1. An aerial vehicle apparatus, comprising:

a lifting propulsion mechanism configured to generate a lift sufficient to maintain the aerial vehicle apparatus at an altitude;

a first maneuverability propulsion mechanism;

a second maneuverability propulsion mechanism;

a third maneuverability propulsion mechanism;

a fourth maneuverability propulsion mechanism;

a fifth maneuverability propulsion mechanism;

a sixth maneuverability propulsion mechanism; and
wherein:

the first maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, and the fifth maneuverability propulsion mechanism are aligned in a plane and oriented in a first direction; and

the second maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, and the sixth maneuverability propulsion mechanism are aligned in the plane and oriented in a second direction that is approximately perpendicular to the first direction.

2. The aerial vehicle apparatus of claim 1, wherein the lifting propulsion mechanism is in the plane and oriented in the first direction.

3. The aerial vehicle apparatus of claim 1, wherein generating with the second maneuverability propulsion mechanism a first force having a first magnitude and a first direction, and generating with the fourth maneuverability propulsion mechanism a second force having the first magnitude and a second direction results in a combined force having a third magnitude and a third direction that surges the aerial vehicle apparatus in the third direction.

4. The aerial vehicle apparatus of claim 1, wherein generating with the second maneuverability propulsion mechanism a first force having a first magnitude and a first direction, generating with the fourth maneuverability propulsion mechanism a second force having the first magnitude and a second direction, and generating with the sixth maneuverability propulsion mechanism a third force having a second magnitude and a third direction results in a combined force having a third magnitude and the third direction that sways the aerial vehicle apparatus in the third direction.

5. The aerial vehicle apparatus of claim 1, wherein each of the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, the fifth maneuverability propulsion mechanism, and the sixth maneuverability propulsion mechanism, are arranged radially around a central portion of the aerial vehicle apparatus.

6. The aerial vehicle apparatus of claim 5, wherein the lifting propulsion mechanism is at the central portion of the aerial vehicle apparatus.

7. An aerial vehicle apparatus, comprising:

a lifting propulsion mechanism configured to generate a force that is approximately equal in magnitude and opposite in direction from a gravitational force acting on the aerial vehicle apparatus;

a first maneuverability propulsion mechanism;

a second maneuverability propulsion mechanism;

a third maneuverability propulsion mechanism;

a fourth maneuverability propulsion mechanism;

a fifth maneuverability propulsion mechanism;

a sixth maneuverability propulsion mechanism; and

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wherein:

at least one of the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, the fifth maneuverability propulsion mechanism, and the sixth maneuverability propulsion mechanism is horizontally aligned; and

at least one of the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, the fifth maneuverability propulsion mechanism, and the sixth maneuverability propulsion mechanism is vertically aligned.

8. The aerial vehicle apparatus of claim 7, wherein:

each of the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, the fifth maneuverability propulsion mechanism, and the sixth maneuverability propulsion mechanism are within a plane and extend radially around a central portion of the aerial vehicle apparatus.

9. The aerial vehicle apparatus of claim 7, further comprising:

a first arm extending from a central portion of the aerial vehicle apparatus;

a second arm extending from the central portion of the aerial vehicle apparatus;

a third arm extending from the central portion of the aerial vehicle apparatus;

a fourth arm extending from the central portion of the aerial vehicle apparatus;

a fifth arm extending from the central portion of the aerial vehicle apparatus; and

a sixth arm extending from the central portion of the aerial vehicle apparatus.

10. The aerial vehicle apparatus of claim 9, wherein:

the first maneuverability propulsion mechanism is coupled to an end of the first arm;

the second maneuverability propulsion mechanism is coupled to an end of the second arm;

the third maneuverability propulsion mechanism is coupled to an end of the third arm;

the fourth maneuverability propulsion mechanism is coupled to an end of the fourth arm;

the fifth maneuverability propulsion mechanism is coupled to an end of the fifth arm; and

the sixth maneuverability propulsion mechanism is coupled to an end of the sixth arm.

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11. The aerial vehicle apparatus of claim 10, wherein:

each of the first arm, the second arm, the third arm, the fourth arm, the fifth arm, and the sixth arm extend radially from a center portion of the aerial vehicle apparatus.

12. The aerial vehicle apparatus of claim 11, wherein:

each of the first arm, the second arm, the third arm, the fourth arm, the fifth arm, and the sixth arm are in a same plane.

13. The aerial vehicle apparatus of claim 10, wherein:

the first arm and the second arm are in different planes.

14. The aerial vehicle apparatus of claim 10, wherein:

each of the first arm, the second arm, the third arm, the fourth arm, the fifth arm, and the sixth arm extend in different directions from the central portion of the aerial vehicle apparatus.

15. An aerial vehicle apparatus, comprising:

a lifting propulsion mechanism configured to generate a lift sufficient to maintain the aerial vehicle apparatus at an altitude;

a first maneuverability propulsion mechanism;

a second maneuverability propulsion mechanism;

a third maneuverability propulsion mechanism;

a fourth maneuverability propulsion mechanism;

a fifth maneuverability propulsion mechanism; and

wherein:

the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, and the third maneuverability propulsion mechanism are oriented in a first direction; and

at least one of the fourth maneuverability propulsion mechanism and the fifth maneuverability propulsion mechanism are oriented in a second direction that is different than the first direction.

16. The aerial vehicle apparatus of claim 15, wherein at least one of the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, or the fifth maneuverability propulsion mechanism includes at least one of a fan, a jet, a turbojet, a turbo fan, or a jet engine.

17. The aerial vehicle apparatus of claim 15, further comprising:

a sixth propulsion mechanism.

18. The aerial vehicle apparatus of claim 15, further comprising:

at least one propulsion mechanism controller operable to control each of the first maneuverability propulsion mechanism, the second maneuverability propulsion mechanism, the third maneuverability propulsion mechanism, the fourth maneuverability propulsion mechanism, or the fifth maneuverability propulsion mechanism during an aerial flight of the aerial vehicle apparatus.

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